Meat quality characteristics of male and female common eland (*Tragelaphus oryx*)

by

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Declaration

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Summary

This study investigated the factors that determine meat characteristics, composition and overall meat quality of male and female Cape eland (*Tragelaphus oryx oryx*) muscles (*Longissimus thoracis et lumborum, Biceps femoris, Semimembranosus, Semitendinosus, Infraspinatus* and *Supraspinatus*). This was done by gathering data on the chemical composition (moisture, protein, fat and ash contents), physical attributes (pH, drip and cooking loss, colour and tenderness), sensory analysis, fatty acid profile and ageing of the selected muscles.

Females (n=6) had a mean live weight of 357.2 kg and males (n=6) 305.4 kg, with cold carcass weights of 162.4 kg and 153.8 kg, respectively. Dressing percentages were calculated from the warm carcass weight and was similar for females and males (48.6 % and 50.8 %, respectively). The LTL (3.99-4.21 kg), BF (3.27-4.04 kg) and SM (3.39-3.75 kg) were the heaviest of the seven muscles removed from the carcass and was on average three to four times the size of the IS (1.15-1.32 kg), SS (0.86-1.15 kg), PS (0.99-1.22 kg) and ST (1.33-1.60 kg). Furthermore eland offer a significant portion (around 26 % of the warm carcass weight, excluding the head) of edible offal due to their large size.

The ultimate pH of all the muscles fell within the normal range (5.5-5.9), although the IS (which had the highest pH) displayed physical signs of DFD compared to the other muscles. Most of the physical measurements were normal for red meat, except for the shear force being higher than for other game species with the LTL having the highest shear force (97.6 N). The CIE colour measurements were in line with what is expected from game meat (L* = 32.3-37.5, a* = 12-15.5 and b* = 10.6-12.9). The proximate composition of the muscles did not vary and was in line with the composition of other game species except for having slightly higher moisture contents (75.6-77.8 %) and proportionally lower protein contents (20.3-23.0 %).

During the sensory evaluation the overall aroma intensity recorded for eland was quite high (68.3 out of 100) and was strongly correlated (r = 0.926) to beef-like aroma. Unwanted aroma and flavour attributes such as gamey (19.9 and 18.3 out of a 100 for aroma and flavour, respectively), livery (1.3 and 1.2) and metallic (5.1 and 9.6) did not play a significant role in the overall profile of the meat. The discriminant analysis plot showed a clear distinction between male and female LTL's, while the BF's were grouped closer together. Overall the BF

(72 and 68 for aroma and flavour intensity, respectively) was rated higher for aroma and flavour than the LTL (65.5 and 62.7); this was supported by the variable loadings plot showing a stronger association with the BF than LTL for most of the sensory attributes. The BF also had higher amounts of most fatty acids (17.94 mg/g total fatty acids, compared to 12.36 for the LTL), possibly linked to a higher intramuscular fat. The fatty acid profile for eland is promising since the P:S ratio was between 0.4 and 0.6, with the bulk of the saturated fatty acids made up by stearic acid (around 78 % of the SFA's). The n-6:n-3 ratio was also lower (1.01-1.77) than recorded before, further supporting the fact that free range game can be considered as a healthier alternative to intensively farmed livestock.

An ageing trial was conducted in order to establish the optimum ageing period for the LTL and BF muscles. An increase in tenderness (57.3 N) was witnessed up to day 28 post-mortem of ageing. Both purge and drip losses increased (2.5 and 1.3 % increase, respectively) throughout ageing, while cooking loss decreased (1.3 %). Meat surface colour turned brighter, more red (CIE a* = 15.6 on day 35) and yellow (CIE b* = 12.7 on day 35) with time. Hue-angle values only increased up to day 17 (41.4), whereas chroma continued to increase up to day 35 (20.2). Sex did not affect any of the measurements. Initially the BF was more tender, had less purge loss and higher CIE a* and b* values than the LTL, however as the ageing period progressed the differences between the muscles became less apparent.

In conclusion, it was found that the structural, sensory and biochemical properties of the meat of eland are not as strongly influenced by sex as they are by muscle type. Furthermore results compared favourably with previous studies on game animals, as well as domestic animals, paving the way forward for eland domestication and meat production.

Opsomming

Die fokus van hierdie studie was om ondersoek in te stel rakende die faktore wat vleiskwaliteit en -samestelling en gevolglik die algehele kwaliteit beïnvloed van manlike en vroulike Kaapse eland (Tragelaphus oryx oryx) spiere (*Longissimus thoracis et lumborum, Biceps femoris, Semimembranosus, Semitendinosus, Infraspinatus and Supraspinatus)*. Dit was gedoen deur data in te samel rakende die chemiese samestelling (vog, proteïen, vet en as) en fisiese eienskappe (pH, drup- en kookverlies, kleur en taaiheid), asook 'n sensoriese analise, vetsuur profiel en veroudering van geselkteerde spiere te voltooi.

Daar is bevind dat koeie (n=6) se gemiddelde lewendige gewig was 357.2 kg en bulle (n=6) 305.4 kg, met koue karkas gewigte van 162.4 kg and 153.8 kg onderskeidelik. Afslag persentasies was bereken deur gebruik te maak van die warm karkas gewigte en was soortgelyk vir koeie en bulle (48.6 % en 50.8 %, onderskeidelik). Die LTL (3.99-4.21 kg), BF (3.27-4.04 kg) en SM (3.39-3.75 kg) was die swaarste van die sewe spiere wat verwyder is en was gemiddeld drie tot vier keer die grootte van die IS (1.15-1.32 kg), SS (0.86-1.15 kg), PS (0.99-1.22 kg) en ST (1.33-1.60 kg). Elande bied ook 'n aansienlike porsie afval (rondom 26 % van die warm gewig, uitsluitende die kop) as gevolg van hul grootte.

Al die spiere se pH lesings was normaal (5.5-5.9), alhoewel die IS (met die hoogste pH) fisiese tekens van DFD getoon het in vergelyking met ander spiere. Die meerderheid van die fisiese metings was normaal vir rooivleis, behalwe dat die taaiheid hoër was as vir ander wildspesies met die LTL wat die taaiste was (97.6 N). Die CIE kleur metings was ook in lyn met wat verwag word vir wildsvleis (L^* = 32.3-37.5, a^* = 12-15.5 en b^* = 10.6-12.9). Die chemiese samestelling van die spiere het nie baie varieer nie en was ook ooreenstemmend met vorige studies op wildsvleis, behalwe dat die vog inhoud (75.6-77.8 %) effens hoër was en die proteïen inhoud (20.3-23.0 %) proporsioneel laer was met vog inhoud.

Gedurende die sensoriese analise was die algehele aromatiese intensiteit van die eland vleis taamlik hoog (68.3 uit 'n 100) en was daar 'n sterk korrellasie (r = 0.926) met 'n beesagtige aroma. Ongewenste aroma en geur eienskappe soos wildagtig (19.9 en 18.3 uit 'n 100 vir aroma en geur onderskeidelik), lewerig (1.3 en 1.2, onderskeidelik) en metaalagtig (5.1 en 9.6, onderskeidelik) het nie 'n groot rol in die algehele sensoriese profiel van die vleis gespeel nie.

Die diskriminante analitiese plot het ‘n duidelike onderskeid tussen manlike en vroulike LTL’s getoon, terwyl die BF’s nader aan mekaar gegroepeer was. Die BF (72 en 68 uit ‘n 100 vir aroma en geur intensiteit onderskeidelik) is gekenmerk aan ‘n algehele hoër aroma en geur gradering as die LTL (65.5 en 62.7, onderskeidelik), dit is ondersteun deur die veranderlike beladingsplot wat getoon het dat meeste van die sensoriese eienskappe met die BF eerder as die LTL geassosieer het. Die BF het ook hoër hoeveelhede van meeste vetsure bevat (17.94 mg/g totale vetsure, in vergelyking met 12.36 vir die LTL), moontlik gekoppel aan meer intramuskulêre vet in die BF. Die vetsuur profiel van eland vleis was belowend aangesien die P:S ratio tussen 0.4 en 0.6 was met steariensuur wat die meerderheid van die versadigde vetsure opgemaak het (ongeveer 78 %). Die n-6:n-3 ratio was ook laer (1.01-1.77) as voorheen gemeet en dit ondersteun die feit dat vrylopende wild beskou kan word as ‘n gesonde alternatief tot intensief geboerde vee.

‘n Verouderingsproef is uitgevoer om te bepaal wat die optimum verouderingsperiode is vir die LTL en BF spiere. Taaiheid van die vleis het afgeneem (57.3 N) tot en met 28 dae na dood. Beide verouderingsvog en drup verliese het verhoog (2.5 en 1.3 % verhoging, onderskeidelik) gedurende die verouderingstydperk, terwyl kook verlies afgeneem het (1.3 %). Die vleis se oppervlak kleur het helderder, meer rooi (CIE a* = 15.6 op dag 35) en geel (CIE b* = 12.7 op dag 35) geword met tyd. Kleur-hoek waardes het slegs verhoog tot en met dag 17 (41.4), terwyl chroma aanhoudend verhoog het tot en met dag 35 (20.2). Geslag het nie enige van die metings beïnvloed nie. Aanvanklik was die BF sagter, met minder verouderings-vog verlies en hoër CIE a* en b* waardes as die LTL, maar verskille tussen die twee spiere het weggeval soos die verouderingstydperk toegeneem het.

Ten slotte word die strukturele -, sensoriese - en biochemiese eienskappe van eland vleis nie soveel deur geslag beïnvloed soos dit deur spiersoort beïnvloed word nie. Verder het resultate goed vergelyk met vorige studies op wildsvleis, sowel as plaasvee, wat belowend is vir die makmaak en vleisproduksie van elande.

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Abbreviations

LTL	*Longissimus thoracis et lumborum* muscle
BF	*Biceps femoris* muscle
SM	*Semimembranosus* muscle
ST	*Semitendinosus* muscle
IS	*Infraspinatus* muscle
SS	*Supraspinatus* muscle
mg	milligram
g	gram
kg	kilogram
cm	centimetre
ha	hectare
DFD	Dark Firm and Dry meat
IMF	Intramuscular Fat
SFA	Saturated Fatty Acids
MUFA	Monounsaturated Fatty Acids
PUFA	Polyunsaturated Fatty Acids
P:S	Polyunsaturated to Saturated Fatty Acid Ratio
n-6:*n*-3	Omega-6 to Omega-3 Fatty Acid Ratio
ALA	Alpha-linolenic Acid
EPA	Eicosapentaenoic Acid
DHA	Docosahexanenoic Acid
pH45	pH at ≈45 min post-mortem
pH24	pH at ≈24 h post-mortem
WHC	Water Holding Capacity
LSMeans	Least Squares Means
SEM	Standard Error of the Mean

Contents

Chapter 1: Introduction

1.1 General introduction

The human population is closing in on the 9 billion mark and is said to pass this figure by 2050. World leaders, government organizations and agriculturalists are feeling the pressure to increase food production for the millions of people around the world and those to come. Together with the need for innovative, efficient methods of farming and producing food there is an increasing awareness of how food is produced and the ultimate effect these practises have on our planet. The challenge for scientists and agriculturalists is therefore to find a middle ground where production is increased in a way that is responsible and sustainable for the environment.

In recent years traditional agriculture, especially regarding livestock, has been highlighted as one of the major contributors to global greenhouse gas emissions (Ericksen et al., 2009). As developed countries focus their attention on implementing measures to control and resolve this problem, developing countries are still facing challenges such as food security, poverty, undeveloped infrastructure, corruption etc. Therefore generalized solutions to problems regarding agriculture is simply not possible, instead solutions need to be relevant to individual scenarios and circumstances.

The ultimate purpose of this study was thus to investigate the possibility of incorporating game species, specifically eland, into a farming system in areas where resources are limited with environmental conditions that are often too extreme for domestic livestock. Game species are relevant to South African circumstances since they are part of the natural make-up of the country and have played an important part in the agricultural and tourism sectors. The focus has traditionally been on creating and improving grazing areas for livestock and consequently trying to adapt these animals (often from European descent) to new environments (Carruthers, 2008). However this method does not make sense if natural fauna and flora is removed to make way for less adapted species that need more input costs just to produce at an equivalent level.

Incorporating game species into the farming model has many advantages such as better adaptation to specific environments, more effective utilization of the natural vegetation and resistance to parasites, diseases and harsh climates (Flack, 2013; Skinner, 1984). These benefits together with the high value of most game species compared to livestock has stimulated the South African game ranching industry's steady growth over the past 15 years and is now the sixth largest contributor to the agricultural industry (Carruthers, 2008; Otieno & Muchapondwa, 2016). While most of the industry's focus has been on trophy and leisure hunting as well as live sales, there is growing interest in domestication of wildlife, especially for meat production purposes (Hoffman, 2007). The game meat market of South Africa has never really developed to its full potential, since the meat was previously only seen as a by-product of trophy hunting. Following a decrease in live sale prices and an increasing number of surplus animals (due to the developing colour variant industry, conservation programs, etc.) farmers are pressured to look into alternative ways to maximize the value of each animal. The sale of game meat has the potential to provide farmers with a more sustained income and at the same time supplement South Africa's red meat market.

Although game species are better adapted to South Africa's environments and require less input costs and management to produce meat there has been little research published on the nutritional quality and characteristics of game meat. This information is needed to inform consumers of the benefits of game meat consumption, but also to establish basic guidelines and regulations if the game meat industry is to expand to its potential. While red meat is highly valued to decrease malnutrition and improve food security in developing countries (McNeill & Van Elswyk, 2012), consumers in developed countries associate red meat with health problems (Wilcox et al., 2009) related to high fat and cholesterol contents (Higgs, 2000). Game meat is considered to be an attractive alternative to traditional red meats, because of its leanness, exotic appeal and the fact that it can be marketed as "free range" and "organic" (Hoffman & Wiklund, 2006). Moreover game meat from South African species has been reported to have high protein contents, low energy and cholesterol contents and healthy fatty acid profiles (Hoffman et al., 2004).

Even though the eland has previously been identified for possible domestication and is well-known for its exceptional meat quality, there has only been a few documented attempts to intensively farm these large ungulates (Posselt, 1963; Skinner, 1971). Consequently research on captive eland herds is limited and even more so for wild eland. When comparing red meats or more specifically game meat, one cannot assume that different species will have similar profiles considering all the factors that determine the final meat quality and composition of an animal's carcass. These factors can either be intrinsic such as sex, level of maturity, muscle location/function, etc. or extrinsic such as environmental conditions, plane of nutrition, management interventions (castrating, feed additives, antibiotics), daily activity levels, etc. (Lawrie & Ledward, 2006; Neethling et al., 2016). Already when comparing animals raised in an intensive system to those farmed extensively there is clear differences in production measurements as well as nutritional and physical composition of the meat. Therefore scientific information needs to be gathered on all species in their separate habitats and presented in a way that will promote future regulations and marketing in the game meat industry.

Subsequently this research aims to build on previous studies by Hoffman & colleagues (2015) and Bartoň & colleagues (2014) by gathering information on the carcass yield measurements, physical analysis, proximate analysis, fatty acid analysis, sensory trail evaluation and ageing of the common eland meat from the Western Cape in South Africa. These tests will hopefully highlight the benefits of eland meat and encourage further more in depth studies.

1.2 References:

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (Taurotragus oryx) and cattle (Bos taurus) raised under similar conditions. Meat Science, 96, 346–352.

Carruthers, J. (2008). "Wilding the farm or farming the wild"? The evolution of scientific game ranching in South Africa from the 1960s to the present. *Transactions of the Royal Society of South Africa*, 63, 160–181.

Ericksen, P. J., Ingram, J. S., & Liverman, D.M. (2009). Food security and global environmental change: emerging challenges. *Environmental Science & Policy*, 12, 373–377.

Flack, P. (2013). *Hunting the Spiral Horns: Eland, Everyman's Elephant*. Johannesburg: Rowland Ward Publications.

Higgs, J. D. (2000). The changing nature of red meat: 20 years of improving nutritional quality. *Trends in Food Science & Technology*, 11, 85–95.

Hoffman, L. C. (2007). The Meat We Eat: are you game? In Inaugural lecture. Stellenbosch University, Western Cape, South Africa.

Hoffman, L. C., Muller, M., Schutte, D. W., & Crafford, K. (2004). The retail of South African game meat: current trade and marketing trends. *South African Journal of Wildlife Research*, 34, 123–134.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, 74, 197–208.

Hoffman, L. C., Van Schalkwyk, D., McMillin, K. W., & Kotrba, R. (2015). Intramuscular fat characteristics of Namibian common eland (Tragelaphus oryx). African Journal of Wildlife Research, 45, 312–320.

Lawrie, R. A., & Ledward, D. A. (2006). Factors influencing the growth and development of meat animals. *Lawrie's Meat Science*, 15-40. Cambridge: Woodhead Publishing.

McNeill, S., & Van Elswyk, M. E. (2012). Red meat in global nutrition. *Meat Science*, 92, 166–173.

Neethling, J., Hoffman, L. C., & Muller, M. (2016). Factors influencing the flavour of game meat: A review. *Meat Science*, 113, 139–153.

Otieno, J., & Muchapondwa, E. (2016). Agriculture and adaptation to climate change : The Role of wildlife ranching in South Africa. Economic Research Southern Africa, working paper no. 579.

Posselt, J. (1963). The domestication of the eland. *Rhodesian Journal of Agricultural Research*, 1, 81-87.

Skinner, J. D. (1971). Productivity of the eland: an appraisal of the last five years' research. *South African Journal of Science*, December, 534–539.

Skinner, J. D. (1984). Selected species of ungulates for game farming in Southern Africa. *Acta Zoologica Fennica*, 172, 219-200.

Wilcox, S., Sharkey, J. R., Mathews, A. E., Laditka, J. N., Laditka, S. B., Logsdon, R. G., Liu, R. (2009). Perceptions and Beliefs about the Role of Physical Activity and Nutrition on Brain Health in Older Adults. *The Gerontologist*, 49, 61-71.

Chapter 2: Literature review

2.1. Background

2.1.1 Genus: ***Tragelaphus*** (Wagner, 1855)

Eland were originally placed in the genus *Taurotragus* in 1855 in the journal of Säugthiere in Abbildungen nach der Natur, mit Beschreibungen which translates to "Figures of mammals in nature, with descriptions" by Johann Andreas Wagner (Wilson & Reeder, 2005). Eland are part of the spiral horn tribe, Tragelaphini (Blyth, 1863), together with Sitatunga, Nyala, Bushbuck, Kéwel, Mountain Nyala, Lesser Kudu and Greater Kudu (Estes, 1991). The tribe has two genera, *Tragelaphus* and *Taurotragus*. Up until recent years eland were the only species separated in the *Taurotragus* genus (Harper, 2001). However, eland were reassigned to the genus *Tragelaphus* following molecular phylogenetic studies and proof that the genus can hybridize with the greater kudu (*Tragelaphus strepsiceros*) and the sitatunga (*Tragelaphus spekii*) (Flack, 2013; Furstenburg, 2017). Some still refer to the genus as Taurotragus on the basis that it separated from Tragelaphus at the end of the Late Miocene (Ropiquet, 2006). Some in the international taxonomical community still include eland in the genus *Taurotragus*, because the molecular evidence proposing to include them into *Tragelaphus* was done on mitochondrial DNA and the mentioned hybrids were infertile.

It is generally accepted that the genus *Tragelaphus* can be divided into two species namely the Common eland (*Tragelaphus oryx*) and the Derby or Giant eland (*Tragelaphus derbianus*). These two species are then further divided into five sub-species which are spread across Africa. The common eland has three sub-species namely: Livingstone's eland, Cape eland and Patterson's eland. It is debated whether these three actually qualify as being separate species since their differences are more phenotypic than genetic (Kingdon & Hoffmann, 2013). The derby eland only has two sub-species namely: the Western derby eland and Central derby eland.

Coat colour between the two species varies from a dull, sandy grey to a reddish, chestnut brown with older males turning grey blue as they mature past the age of 6 years (Hillman, 1979) as a result of hair loss (Lyell, 1987). Males from both species have a tuft of hair on their foreheads which also becomes more prominent with age (Kingdon, 2001). Most eland have a black dorsal stripe and darker colouring around the lower part of the neck (Kingdon, 2001).

This feature is more characteristic to the *T. derbianus* species as you move up to the north of Africa and fades away as you move down to the Cape eland in South Africa (Posselt, 1963). Species of *T. derbianus* have between 8 and 16 vertical white stripes, which is usually not a feature on their Cape cousins in the south. Although the Cape eland has no stripes the other two sub-species of *T. oryx* have varying amounts of stripes from 5 to 14 depending on location and hybridization between species.

Both males and females have horns, males have shorter, thicker horns with more pronounced spirals and females have longer, slender horns with less distinct spirals. Both sexes have the dewlap but once again this feature is more pronounced on the males and also stretches with maturity (Kingdon & Hoffmann, 2013). In the *T. derbianus* species the dewlap stretches from the chin whereas it starts around the throat of the *T. oryx* (Kingdon, 1982). Common eland generally have shorter legs and a stocky build much like that of a beef steer and weights of over a ton are not unheard of. Their front hooves are also larger to support the enormous weight of the neck, shoulders and chest. The giant eland's name is actually misleading as it refers to the horns of the animal and not the actual body size (Flack, 2013). Their horns can reach lengths of between 80-123 cm, therefore they are prized trophies (Kingdon, 1982). Horns of the common eland are shorter (43-67 cm for males and 51-70 cm for females), with a larger posterior keel and spaced further apart (Gentry, 1978). The ears of the common eland has a thin, elongated shape and the derby eland's ears are wider and rounded.

2.1.1.1 Subspecies: **Cape eland (*Tragelaphus oryx oryx*)**

Cape eland were first introduced to the world of science in 1766 by the German zoologist Peter Simon Pallas, who described eland as part of his book *Miscellanea Zoologica* (Pappas, 2002). The eland that Pallas described were part of the Dutch museum collections gathered by early settlers in the Cape of Good Hope.

This phenotype of eland is the most abundant throughout Africa and is likely responsible for crossbreeding with other species resulting in a dispersal of forms, although these hybridizations have not been scientifically studied. They are generally found in South Africa, with their territory extending up to the southern parts of Namibia and Botswana and the very south of Mozambique (Flack, 2013). Older males are known for their grey blue colour and are often referred to as "blue bulls", the blue tinge is said to be the consequence of higher androgen levels during the rutting season (Bro-Jørgensen, 1997), but is also related to hair loss due to old age. Females and younger males are a dull fawn colour (Flack, 2013). The black dorsal stripe and mane are not normally a distinct feature on Cape eland although some populations will have a darker dorsal stripe potentially due to selection or environmental influences. Cape eland also lack the vertical stripes visible on the flanks of other subspecies in the genus, although younger animals sometimes have light stripes. Once again, due to translocations throughout southern Africa, possible hybridization with especially *T. o. livingstonii* has resulted in some phenotypes with between 1 to 5 stripes.

Adult Cape eland have a body length of 200-345 cm and a tail length of 60-90 cm. Males have an average shoulder height of 170 cm and females, 150 cm. Bulls have a body weight of 650-940 kg and cows 400-560 kg (Kingdon & Hoffmann, 2013). In the Drakensberg Mountain region of South Africa, eland are much smaller and males only reach a maximum mass of 500 kg. This difference in size could be the consequence of lower nutrition levels due to prevailing grasslands and the greater expense of energy to move up and down the mountain slopes and to cope with harsh winters (Jeffery & Hanks, 1981).

The Cape eland easily adapts to different elevations and types of habitat including Nama Karoo, Succulent Karoo, Cape Fynbos as well as Savannah and arid grasslands of South Africa (Flack, 2013). They are not territorial and their movement is generally determined by the surrounding food sources on offer. They are mainly browsers, but their diet will also include green grass if available in the summer (Posselt, 1963). They are also known for eating twigs, fruits, berries, tubers and dry fallen leaves. Home ranges in the wet season can vary from 174-422 km^2 but during the dry season their movements are limited to an area of 9-58 km^2 (Castello, 2016).

Their family groups are normally between four and twelve animals although given the opportunity and numbers they will form aggregations of up to 700 animals (Kingdon & Hoffmann, 2013). Social organization follows a strict dominance hierarchy and the formation of bachelor and nursery herds is also common. During the winter months large herds will split up into smaller herds of 4-10 animals of both sexes and all age classes.

Their conservation status is of least concern.

2.1.1.2 Subspecies: **Livingstone's eland (*Tragelaphus oryx livingstonii*)**

Livingstone's eland were first described to scientists by the English lawyer and zoologist Philip Lutley Sclater in 1864. Sclater was actually better known for his work on birds in North America, but during his time as secretary of the Zoological society of London he had the opportunity to describe other species such as *Okapia johnstoni* and *T. o. livingstonii*. The latter was named after the Scottish missionary David Livingstone, who spent 32 years of his life in Africa trying to convert natives to Christianity. He briefly describes the eland cow that was shot and named after him in his book Missionary Travels and Researches in South Africa (published in 1857) (Flack, 2013).

This sub-species of *Tragelaphus oryx* is located in the geographical area between that of southern *T. o. oryx* and the northern *T. o. pattersonianus* species. However these days many of the remaining populations are kept on private rangelands and intensively managed due to their high economic value and therefore wild herds are rare.

Compared to the Cape eland, *T. o. livingstonii* has a rufous fawn coat, typically brighter in younger animals and progressively fading with age (Posselt, 1963). Both sexes have a deeper colouring on the saddle with a dark dorsal stripe. This sub-species commonly has 6-10 thin white stripes running from the dorsal down the flanks (Castello, 2016). Older bulls are also blue-grey to dark grey and lose their stripes with age as their coat colour fades. Females on the other hand tend to hold on to their stripes since their coats do not fade as much and provides enough contrast for the stripes to be visible (Kingdon & Hoffmann, 2013). Mature bulls have the characteristic tuft of hair on their foreheads which has a dark chocolate colour. Variations between populations include males with a darker nose leading into the forehead tuft and populations with a white chevron under the eyes. As with the Cape eland the dewlap only starts at the throat. Both males and females also have the black patch behind the knee and are darker around the hooves. According to WRSA Wildlife rancher of the year 2012, Ellalien Davey, there should be a balance when selecting a great eland. However she admits that the market for this animal is driven by colour and therefore the breeders will always choose a better coat over longer horns.

The body length for an adult animal is normally between 200-345 cm (Castello, 2016). Bulls measure an average of 170 cm at the shoulder and cows 150 cm (Castello, 2016). Their tails are 60-90 cm long ending in a black tuft. The males weigh between 650-910 kg and females between 400-600 kg (Kingdon & Hoffmann, 2013). The horns of the female (68 cm) is longer than that of the male (65 cm), but *T. o. livingstonii* bulls have somewhat longer horns than the bulls from the other two sub-species (Flack, 2013).

Their distribution stretches from the northern tip of South Africa up through Namibia, Botswana, Zimbabwe, Zambia and the extreme south of Tanzania, the Livingstones in Angola are possibly extinct while numerous translocations have taken place to South Africa. Their preferred habitat ranges from mountainous areas to semi-desert regions with open plains and wooded areas for cover (Flack, 2013).

Their family groups consist of both sexes and different ages and will normally contain anything between 25-70 animals (Kingdon & Hoffmann, 2013). Their behaviour is normally gregarious although they have an open and fluid herd structure (Castello, 2016). Their natural behaviour is nomadic therefore they will travel distances of more than 250 km within their home range (Castello, 2016). The bulls are also less territorial and it is common for animals to form large groups of up to 100 strong.

2.1.1.3 Subspecies: **Patterson's eland (*Tragelaphus oryx pattersonianus*)**

Patterson's eland or the East African eland was first described by English naturalist Richard Lydekker in 1907 and these descriptions were published in his book *The Game Animals of Africa,* published in 1908 by Rowland Ward. The person who supplied this new found antelope to the British Natural museum was Lieut-Col. J.H. Patterson who discovered and shot the animal in 1907 on safari in East Africa (Flack, 2013).

This sub-species of the common eland is much like its neighbour the Livingstone in terms of coat pattern and general appearance. The cows have a rufous fawn to tan colour and the bulls a grey fawn colour (Flack, 2013). Their flanks also carry the thin white stripes but compared to the other two species they generally have more stripes (up to 12). Again this can vary between populations of Patterson's because of cross breeding. Some of the other features that may aid in distinguishing an East African eland include a darker primary coat colour, chestnut colouring on the sides of the forehead and normally a white chevron under the eyes (Kingdon, 2001). The horns are also said to be shorter compared to the other two sub-species. A dark dorsal stripe is prominent on the East African eland and cows have a slightly longer dorsal mane from the neck to behind the shoulder as well as a bigger dewlap tuft than that of other sub-species (Kingdon, 1982). When looking at the skull shape of East African and Livingstone eland there is a noticeable difference to that of the Cape eland, which has a vertically longer, narrow shaped face and more upward pointing ears (Castello, 2016). There are also black spots behind the knees of their forelegs and they have a slightly longer tail than the other subspecies with a terminal black tuft (Kingdon & Hoffmann, 2013).

Patterson's eland have a body length that ranges from 200-345 cm and a shoulder height of 130-180 cm (Castello, 2016). Adult males can weigh anything from 400 to 952 kg depending on their age and females generally weigh about 30-35 % less (Jeffery & Hanks, 1981a). This sub-species was formerly native to Ethiopia, Rwanda, Kenya, Sudan, Tanzania and Uganda (Kingdon, 1982). Today their distribution stretches from Tanzania up through south and west Kenya, south-east and north-east Uganda, south-east Ethiopia to south-east Sudan (Kingdon, 1982). They are possibly extinct in Burundi. The habitat of these areas included savannah and open woodlands ranging from sea level to elevations of up to 5 000 m on Mount Kilimanjaro, where a natural mineral lick is found (Castello, 2016).

Their family groups are relatively big in size (25-70 individuals) and groups of up to 400 animals have been observed (Kingdon & Hoffmann, 2013). Being a gregarious species they will always form large herds, but their home range size varies significantly regarding sex and season. In the dry season bulls will use roughly 12 km^2 of their total 41 km^2 range and females have a dry season range of around 26 km^2 (Hillman, 1988); compared to the wet season when their range expands to 220 km^2 (Castello, 2016).

As for their conservation status they are listed as least concern. There is a healthy population of 36 000 in Tanzania, but as is the case with most African wildlife they are also threated by poachers and loss of habitat (Castello, 2016).

2.1.1.4 Subspecies: **Western Derby eland (*Tragelaphus derbianus derbianus*)**

The Western Derby eland or Lord Derby's eland was first described in 1847 by British zoologist John Edward Gray. These descriptions were based on skins and horns of a bull and cow from the River Gambia area, which he received from J. Whitfield, a collector who was employed by the Earl of Derby (Flack, 2013). The existence of these enormous animals was confirmed by the well-known African traveller Winwood Reade in 1862 when he visited the same region

(Flack, 2013). They were named in honour of Edward Smith-Stanley, the 13th Earl of Derby, who first introduced eland to England's science world.

Their coat colour changes from an amorphous dark chestnut band around the lower neck and dewlap through to a bright fawn colour on the rest of the body (Kingdon, 2001). They are said to be more reddish in colour than the central Derby eland (Kingdon, 1982) but this is possibly due to seasonal moulting that occurs at the same time of year that scientists are able to enter their habitat in Senegal to view them; this recording may therefore be somewhat subjective. Their flanks also carry the white stripes which is more visible on these animals than on the common eland (Castello, 2016). They can have up to 15-17 stripes in varying lengths from the shoulder to the hindquarters (Castello, 2016). Other trademark features include a dark, short-haired dorsal stripe, a black stripe running from under the throat through the front legs towards the back legs, charcoal colouring on the bridge of the nose accompanied by a lighter chevron under the eyes, lips that are lighter in colour with a few lighter spots along the jawline, a thin white collar around the base of the neck, black pasterns with a white patch just above the hoof and big round ears with white edges (Kingdon, 1982).

As mentioned before, the Derby eland is actually smaller in body mass than the common eland, but because of their longer legs and horns they look enormous. Their total body length is 220-290 cm while their shoulder height is 150-175 cm, although taller animals are often encountered (Castello, 2016). Their weight can be anything from 440-900 kg depending on sex and age. Horns measure 80-120 cm, which is significantly longer than the common eland's horns but slightly shorter than the Eastern Derby eland (Flack, 2013). The shape of their horns also differ from the common eland because it is more V-shaped than parallel (Castello, 2016).

This species used to occur in Gambia, Ghana, Guinea, Ivory Coast, Mali, Sudan and Togo (Flack, 2013). However today their numbers have been decimated to between 100-150 animals that are protected in the Niokolo Koba national park in south-east Senegal (Nežerková et al., 2004). Their habitat in this park is a mixture of broad leaved savannah trees and semi-arid Soudanese forest glades (Nežerková et al., 2004). There are also small semi-captive populations in the Bandia and Fathala reserves in Senegal (Flack, 2013). Sightings of animals around Mali and Guinea have been reported (Darroze, 2004), however this study was conducted 14 years ago and if compared to the increase in elephant poaching in Western

Africa the odds are heavily stacked against those remaining populations, especially as eland is regarded as a prized bush meat animal.

In the past herds of up to 75 animals have been reported, however due to their low numbers they are more likely to form groups of between 15-20 animals (Castello, 2016). These groups normally consist of cows with their calves as well as a few juvenile males. The adult bulls prefer to roam on their own. They are known for extensive migration in the dry season and will split into smaller groups that re-join at the start of the wet season (Kingdon, 1982).

Since their numbers are so low and they are restricted to only three locations they have been flagged as critically endangered in the wild (IUCN SSC Antelope Specialist Group, 2008).

2.1.1.5 Subspecies: **Central or Eastern derby eland (*Tragelaphus derbianus gigas*)**

This animal was first described by Martin Theodor von Heuglin in 1863 when he organized an expedition to the White Nile (known today as Sudan) and found the horns of the Eastern Derby eland (Nežerková et al., 2004).

Most of the features that are found on the Western Derby eland are the same on their eastern counterparts. Only morphological differences have been described to the scientific community at this stage (Kingdon, 1982). These include a slightly larger body size, a sandy colour coat and only up to 12 stripes on the torso (Castello, 2016). Other than that, the facial features such as the charcoal coloured bridge, the chevron under the eyes and white lips and white spots around the jaw are the same. They also have slender legs with black and white markings on the front of the pasterns and a black patch behind the knee. The dorsal stripe is also present on the back, darker around the shoulders and ending in a black tuft of hair on the tail. Males have the trademark dewlap starting under the chin and extending down the neck, the colour of this feature is dark brown which is separated from the rest of the sandy body colour by a prominent white necklace. They turn grey with age, lose their stripes but in turn gain the dark chocolate or reddish brown (in the case of the bulls in Sudan) tuft on the forehead.

Central Derby eland average 220-290 cm for their body length with a shoulder height of 150-175 cm (Castello, 2016). As for body weight, they are slightly heavier than the Western Derby with animals normally weighing 440-950 kg (Nežerková et al., 2004). Again the females are smaller than the males and their average weight is about 30 % lighter. Horn lengths are slightly longer than the other sub-species, with an average of a 120 cm (Castello, 2016). Trophies of over a 140 cm have been recorded in the Central African Republic (Flack, 2013).

The eastern sub-species is native to Cameroon, Central African Republic, Chad, Congo and Sudan (Castello, 2016). Their numbers are estimated to be around 14 000 total, spread over northern Cameroon, north-east Central African Republic and south-west Sudan (Flack, 2013). Most of these populations are in reserves such as Bénoué National Park, Faro National Park and Bouba Njida National Park in Cameroon and Manovo-Gounda St. Floris National Park in the Central African Republic (Nežerková et al., 2004). The habitat in these areas is mostly dominated by broad-leaved wooded savannahs and arid forests (Castello, 2016). Due to their high value as trophy animals they are also kept and bred on private game farms in southern African countries such as Zimbabwe, Namibia and South Africa.

Derby eland are known to be highly nomadic with large home ranges and distinct seasonal movements (Kingdon, 1982). Groups of up to 60 animals were common in the past, but with an increasing threat of poaching in these areas their family groups are more likely to be around 15-25 animals (Castello, 2016).

They are listed as low concern on IUCN's red list but potentially vulnerable. Most of the Eastern Derby eland occur in the Central African Republic with an estimated 12 500 animals (IUCN SSC Antelope Specialist Group, 2008). The population in Sudan is estimated to be less than 200 animals (Flack, 2013).

2.2 History of South Africa's wildlife industry and eland domestication.

Domestication of wild antelope dates back thousands of years and according to archaeologists some of the first attempts can be traced back to the African Stone age (Spinage, 1986). Some of the first documented attempts of domestication, dating to around 2400 BC, can be found in the tomb of Mereruka, who served pharaoh Teti during the sixth dynasty of Egypt. On the tomb walls there are scenes of collared gazelle and oryx as well as descriptions of a breeder who managed 3 988 cattle and 1 135 gazelle (Spinage, 1986). Antelope have always formed an important part of the livelihood of Africans, especially as a source of meat referred to as "bush meat" (Davies & Brown, 2008), however until recent decades there has been far less interest in intensive management and farming of antelope, compared to traditional domestic livestock. Nevertheless the idea to domesticate African wildlife has existed since the mid-19th century (Methuen, 1948).

Eland were introduced to Eastern Europe as early as 1892 when Askanya Nova zoo in the Ukraine imported four bulls and four cows of the subspecies *T. o. oryx* (Treus & Lobanov, 1971). They were bred and selected for improved milk and meat quality and after 76 years at the park they had multiplied to a total of 461 eland (Treus & Kravchenko, 1968). After the Second World War their numbers were maintained at around 40 animals in a free-grazing herd (Treus & Lobanov, 1971). A milking herd of 22 eland cows was established in 1948 and the milk was later used in a hospital nearby (Posselt, 1963). Their milk proved to be very nutrient rich, containing three times the amount of fat and twice as much protein as cow's milk (Treus & Lobanov, 1971).

Back in South Africa the future for eland and other wildlife species was looking grim and conservation, never mind domestication was not a priority at the time. The first settlers arrived in the Cape in 1652 under the banner of the Dutch East India Company who at the time was interested in establishing a halfway stop between Europe and India. From the earliest days after establishing the trade post in the Cape, company employees, free burgers, trekboers and traders ventured inland seeking a lifestyle based on hunting and extensive pastoralism (Mossman & Mossman, 1976). Along with the colonial expansion of settlers in South Africa came adventurers such as William Cornwall Harris that called themselves "sportsmen." Being the first recreational hunter to visit the Cape, Harris documented his expeditions in various books including *The Wild sports of Southern Africa (1839),* which became very popular back in Europe (Flack, 2013). These tales of an untouched South Africa with an endless bounty of wildlife enticed many Europeans to follow in his footsteps. More significant, however, were the large Voortrekker parties seeking to claim their part of the land and in the process making partnerships with African mercenary hunters who aided in the extermination of various species (Van der Merwe, 1995). Some of the species who first experienced the destruction of the Europeans included elephants and black wildebeest. In 1855 it was estimated that around 90 000 kg of ivory was exported from the Transvaal, along with vast amounts of antelope skins and horns (Carruthers, 2008). In 1866 a single company in Kroonstad reported exports of around 157 000 black wildebeest (*Connochaetes gnou*) and blesbok (*Damaliscus pygargus phillipsi*) skins (Carruthers, 2008). Almost two million skins were exported from Durban between 1870 and 1880 (Mossman & Mossman, 1976). It would appear that the market for skins was the main driver of game harvesting, while recreational sport-hunting added substantially to their destruction.

During these early days the eland was also a highly prized animal, not only for the large amount of meat that it offered, but also for their hides that were used for wagon gear and fat for candles. Their important value as a source of meat, together with the fact that they could be tired out on horseback within a few kilometres and then conveniently driven back to camp to be slaughtered, meant that these animals were the first choice of hungry settlers craving protein (Flack, 2013). However this form of "hunting" was exploited by recreational hunters such as Harris. African wildlife was seen as an inexhaustible resource in those days and this statement was proven by the way in which hunting expeditions were conducted. For Harris and others that followed in his footsteps driving the eland back to camp proved to be the easiest way to slaughter dozens of eland at a time for their hides and meat or in the case of Harris for their tongues and briskets (Flack, 2013). The fate of the eland populations up north were much the same as that of the Cape eland, they too were slaughtered using this controversial method.

The British foreign services officer Reginald Maugham, who served at various consular posts throughout Africa, gave the following account of the situation regarding eland in his book *Wild Game of Zambezia* (1913):

"I have always expressed the opinion that the eland should never be hunted. On the Contrary, this splendid form should be generously protected, domesticated and utilized. No antelope with which I am acquainted yields such delicate meat or such large quantities of fat and milk, and no other is so easy to tame or would give back such riches for kindness and good usage. There are a few of us doubtless who have shot through East and South Africa during the last twenty years who cannot look back upon a certain number of eland which from time to time have fallen as prizes to our rifles. So far as I am concerned, I can recollect, during the period mentioned, having been responsible for the deaths of five or six of these animals, and their horns are still in my possession or in that of friends upon who I bestowed them; but I must confess that whilst the contemplation of other trophies taken from species possibly as harmless awakens in me no sense of self-reproach, the noble eland heads, which lend dignity to their surroundings, not seldom awaken, as I pass them by, an uneasy feeling almost of regret that I should have lessened, even by so infinitesimal a number, so splendid and useful a detail of Africa's majestic fauna."

This uncontrolled killing along with the rinderpest epidemic that hit South Africa in 1896 led to the widespread extinction of eland populations across the country, but especially in the Western Cape. The views of those who realized how the careless killing has effected eland populations were summed up by the following words of James Stevenson-Hamilton, first warden of the Kruger National Park:

"The largest and most docile of all the antelope in the tribe, the eland has deserved a better fate than the extermination which has overtaken it in most of its favourite homes. The ease however with which it could be destroyed, especially by mounted hunters and the quality of the meat which it provided has, however, in the past too often proved it's death warrant. Thus an animal not only beautiful, gentle and harmless, but one that might have proved a useful servant to Man, had fate ordained that it should live amid enlightened and intelligent human surroundings, is in danger of disappearing off the face of the earth at no very distant date."

After the eventual realization of what was to happen if no one takes responsibility for the situation, a few captive breeding herds were established to replenish the wild populations. One of these projects, which could be considered as one of the first attempts to domesticate eland, was the work of above mentioned game warden, Stevinson-Hamilton (Carruthers, 2008). In 1906 he released a pair of eland into Kruger park and by 1914 they had grown nine members stronger (Carruthers, 2008). They were reported to be very docile animals, returning by themselves after they were out grazing for the day.

Moreover, conservation did not gain much support during the early twenties, largely due to the views of popular field scientists of the day. These views were mostly those of the agriculturalists and veterinarians in government service (Carruthers, 2008). They believed that wildlife spread diseases to livestock and that the government should not waste space on wildlife parks, but rather convert the land for more productive use (Brown, 2005). One example of this radical attitude took place in 1929, when the extermination of 35 000 animals was conducted by the Division of Veterinary Services in the Zululand game reserves

(Carruthers, 2008). The driver behind this massacre was the reserve's location in an area of endemic *nagana* (Trypanosomiasis), which could potentially be passed on to livestock (Brown & Gilfoyle, 2007). Fortunately some farmers thought otherwise and allowed antelope numbers to rise on their farms, provided there was enough separate space for them to roam. This positive attitude favoured wildlife throughout the 1920's and 1930's, and farms with game species on them actually fetched higher prices.

During this period South Africa became part of an international network of scientists who introduced new ways of thinking especially regarding conservation. Scientists such as E. B. Worthington expressed their concerns and blamed "anti-game campaigns" for the decline in wildlife (Worthington, 1938). In his book *Science in Africa* (1938) he argued that agricultural scientists were on the wrong track in trying to improve African livestock breeds, rather than focusing on how wildlife could offer a sustainable protein source for local communities.

From the 1950's and onwards science formed an important part in conservation strategies and general wildlife management. Attitudes towards wildlife changed and so did the value placed on game animals (Carruthers, 2008). Together with this growing economic value in the private sector, interest grew in the science and management of state owned parks. The initial focus of research in national parks fell on cross breading and domestication, with the eland being one of the first species under investigation (Mossman & Mossman, 1976). Work done in the 1920's was revived by the Natal Parks board (Moe, 1953) and Posselt conducted a pilot study in Zimbabwe (Posselt, 1963). In 1956 the Cape Department of Nature Conservation invested in a farm (De Hoop nature reserve, Western Cape) on which the "relationship between wildlife and farming practises" (Nell, 2003) was to be researched. This inspired many intensive game farming attempts to follow in the surroundings and beyond.

Scientists who contributed significantly to the change in attitudes and knowledge of game ranching include the likes of Dassmann & Mossman, Posselt, Talbot and others. Their studies not only provided practical information around sustainable culling and harvesting for game ranches, but also provided much needed information on ecology, biology and biomass figures for animals in the wild. These studies also gave knew insight to the potential meat production of wildlife compared to cattle and reported higher meat production for wildlife per unit area under equal circumstances than cattle (Talbot et al., 1965). By 1964 Transvaal had over 3 000 farms that were home to game animals (Lambrecht, 1983). This was largely due to the fact that land partitioning allowed land owners to contain game, essentially turning it into a private resource (Carruthers, 2008). People could no longer harvest large amounts of game wherever they liked as this could lead to serious trespassing and hunting violations.

More specific work on eland followed in the 60’s and 70’s, not only in South Africa, but abroad as well. One of these research projects took place at the Doddieburn ranch belonging to the Henderson brothers in, what is today, southern Zimbabwe (Retief, 1971). In 1954 John Posselt obtained the necessary permission to catch five eland calves while stationed in the Lupani district (southern Zimbabwe) (Posselt, 1963). He subsequently caught four, raised them on cow’s milk and went on to establish one of the most well know eland domestication projects of his time. When he was transferred to Zezani (southern Zimbabwe) and later again to Doddieburn, his initial herd stayed behind, but additional animals were caught and introduced to his new herd in Beit Bridge (Posselt, 1963). At Doddieburn the herd was taken over by the Department of National Parks, but John remained their supervisor (Skinner, 1971). The Manyoli research centre was established which included an office and separate camp for the eland (Mossman & Mossman, 1976). Posselt’s objective with domesticating the eland was to offer them as an alternative to or to compliment cattle farming in marginal lands with low rainfall or in other areas that were unsuitable for normal large livestock (Posselt, 1963). Along with this he selected for better temperament as well as improved conformation. These eland would later form part of the studies conducted by the American Fullbright scholars, Archie Mossman and Raymond Dassman. The research they conducted at Doddieburn ranch was rather complex and involved everything from population studies, game counts and harvesting quotas through to hunting techniques, physical characteristics and comparative costs of cattle vs. game (Carruthers, 2008). The purpose being to establish scientifically based utilization of wildlife in a sustainable yield basis. It is also at Doddieburn where the term game ranching was coined.

Although the topic of game ranching was becoming more popular under the influence of progressive science, the Department of Agriculture was still not fully on board with these new developments. Still locked in the mind-set of the 1920’s, most in the department were not interested in the concept of game ranching, believing that the risk of disease spread and incorrect veld management would outweigh the potential benefits (Carruthers, 2008).

However, some in the Department did take interest in what Dassman and Mossman initially set out to study in Zimbabwe. Research was lacking or needed to be improved to determine the feasibility of a game ranch setup for commercial production.

Unfortunately the hype around game ranching faded as research shifted to improving domestic livestock breeds such as cattle, sheep and pigs (Carruthers, 2008). Along with this some of the potential benefits of game production that were initially highlighted soon dissipated in the light of more detailed studies (Grossman et al 1999).

Despite initial promise and a high level of research, by 1971 it had been concluded that the prospects of eland ranching had been over estimated since it was very challenging to exploit their advantages in an intensive setup (Carruthers, 2008). These include a higher reproductive rate than *Bos indicus,* physiological and behavioural adaptations to a hot and semi-arid environments and a diet that does not mind poisonous plants (Retief, 1971). These factors benefitting the eland seems to be limited to specific, harsh environments and when the two species would meet on a level playing field cattle would have better economical production (Skinner, 1971). Furthermore it was argued that marketing and regulation of the culling process in these areas would be almost impossible (Skinner, 1966). Besides the need for specialized abattoirs, eland prices made it difficult to establish a profitable herd from scratch (Skinner, 1971).

Despite the interest lost in eland domestication, game farming, particularly in South Africa, as a whole has enjoyed a steady growth since the 80's. Nell (2003) reported a steady increase in the number of game ranchers from around 2 280 in 1980 to 9 000 in 1992 and Van Zyl (2000) estimated an annual growth of 2.5 % for the industry. In 2005 an estimated 9 000 farms were used for wildlife production and a further 15 000 farms featured wildlife alongside cattle production (Patterson & Khosa, 2005). The game farms of the Northern Cape cover the largest area (4 920 ha) out of all the provinces, while Limpopo has the highest percentage (49 %) of individual game farms in South Africa (Van der Merwe & Saayman, 2004). According to the National Agriculture Marketing Committee (NAMC), South Africa's game ranching industry has an annual turnover of about R4.7 billion, of which biltong hunting contributed the largest percentage (66 %) and (formal) meat production the smallest (1 %) (NAMC, 2006).

2.3 Extensive vs. intensive eland production

2.3.1 **Diet differences**

The eland is classified as an intermediate feeder, which means that it has a specific liking for shrubs and forbs (Estes, 1991), but if the need arises or nutrition levels are better they will graze on grasses (Kingdon, 1982). This mixed feeding regime largely depends on the level of crude protein in the plants. Due to their high rate of metabolism, eland prefer more nutritious food to allow for maximum nutrient absorption for the rumen microbes. Where grass normally forms about 33 % of their diet it can increase to 92 % if the protein content is favourable or there are fewer browsing options (Roth et al., 1970). Eland will often be the first animals to move through a burnt piece of land just to secure the freshly formed shoots of various grass species (Flack, 2013). This selective nature can also be witnessed when eland are feeding on other plants, since they target specific parts of a plant, although they have little preference between species (Hofmeyr, 1970).

Eland are not only restricted to grasses and shrubs, but will also consume berries, fruits such as the marula (*Sclerocarua birrea*) and wild plum (*Ximenia Americana*), tubers, seed pods and herbs; whilst eland show a certain degree of resistance against poisonous plants (Flack, 2013). One example of this toxic tolerance is in the Matetsi area, towards the north-western part of Zimbabwe, where there is a plant that goes by the name of umkauzaan (*Dichapetalum cymosum)* (Posselt, 1963). This plant regularly claims livestock that feed on the newly formed shoots of the plant which are extremely poisonous (Mossman & Mossman, 1976). For some reason eland seem to thrive in this area, which proves that they are not as affected by the high toxin levels. They seem to have a resistance to most plants that are not normally included in the diets of domestic animals (Skinner, 1967a). While cattle will leave certain weeds to grow and spread in a pasture, eland will graze everything to the same level. Weeds such as marigold (*Tagetes minuta*), starburr weed (*Acanthospermum australe*), stinging nettle (*Urtica dioica*), blackjack (*Bidens pilosa*) and pigweed (*Amaranthus hybridus*) are amongst their favourites (Posselt, 1963).

There is a considerable difference in the feeding patterns of eland herds spread over different habitats and seasons. At high altitude habitats with cooler weather they tend to alternate between feeding and ruminating at an interval of around two hours until late afternoon before they rest (Van Zyl, 1965). Whereas in hot, dryer areas they tend to pick a shady spot for the day and then only start feeding once the temperature is more suitable (Watson & Owen-Smith, 2000).

In terms of water requirements, eland are not as efficient as certain dessert species, but have definitely evolved some physiological adaptations to lower their dependence on water (Estes, 1991). Eland extract most of the moisture they need from the plants that they consume (Watson & Owen-Smith, 2000). As with other species in the spiral horn tribe they are well equipped to snap branches with their horns in order to access young, juicy shoots where smaller animals cannot reach (Skinner, 1966). Therefore eland do not need a constant water sources to survive, although they will regularly drink if water is available (Furstenburg, 2007). This lowering in the amount of water needed is due to the fact that they are able to gradually increase their body heat during the day, which means they don't have to sweat to cool down and can therefore conserve that moisture (Retief, 1971). Water loss is further improved by excreting dry faeces, concentrating their urine, lowering their metabolic rate and by breathing slower and deeper (Taylor & Lyman, 1967).

The Cape eland has a habitat that includes Kalahari sand-veld, semi-arid regions of Namibia, Namaqualand, Karoo succulent scrub-veld, southern subtropical savannah bushveld, Eastern Cape valley bushveld thickets, Highveld sour grassland and Cape fynbos (Furstenburg, 2007). In these habitats they will consume high protein, succulent leaves from a variety of flowering plants that include *Acacia, Combretum, Commiphora, Diospyros, Grewia, Rhus* and *Ziphus*. Eland may also eat forbs (nonwoody dicotyledons) from the family *Compositae*, including *Acanthospermum, Bidens, Tagestes*, and *Tarchonanthus* plants together with fruits from the *Securinega* and *Strychnos* plants. Dominant grasses include *Setaria* and *Themeda*, while densely wooded forests are avoided.

Hofmeyr (1970) listed around 60 plant species that Patterson's eland fed on in their habitat in south east Ethiopia, including 11 grass species. According to Wilson (1969), a total of 18 different types of leaves and a variety of unidentified grasses were amongst the stomach contents of Livingstone's eland cropped during tsetse fly control operations in eastern Zambia. These animals consumed large amounts of camel's foot (*Piliostigma thonningii*) as well as the fruits of marula, sourplum and monkey orange (*Strychnos* Spp), one animal even had 374 kudu berry (*Pseudolachnostylis maprounefolia*) fruits in his stomach (Wilson, 1969).

The Derby eland inhabits wooded savannah areas, typically trademarked by a high number of *Isoberlina doka* trees (Kingdon, 1982). The Derby eland mainly browses on these trees as well as a few *Julbernadia* trees and young grasses and herbs (Kingdon, 1982). Hejcmanová and colleagues (2010) reported that western Derby eland in Niokolo Koba National Park, their last natural refuge, browsed on leaves, shoots of woody plants and fruits during the dry season. These three components made up 98.8 % of their total diet and consited of leaves of *Boscia angustifolia*, *Grewia bicolor, Hymenocardia acida* and *Ziziphus mauritiana*, and fruits of *Acacia* species and *Strychnos spinosa* (Hejcmanová, Homolka, Antonínová, Hejcman, & Podhájecká, 2010). Forbs and grasses generally did not make up more than 5 % of the diet, but this changes significantly in the wet season (Hejcmanová et al., 2010).

Supplementary diets in semi-intensive systems normally include some concentrate or mineral licks such as calcium-molasses or copper/cobalt stock blocks. Western Derby eland in the Bandia reserve in Senegal, which were also part of the above mentioned study of Hejcmanová and colleagues, received daily supplementation in the dry season. This supplementation consisted of a mixture of livestock granules, groundnut hay and pods of *Acacia albida*. The bulk of their diet (77 %), however, was still made up of the natural vegetation in their camp including several *Acacia* species, *Azadirachta indica*, *Boscia senegalensis*, *Combretum micranthum*, *Grewia bicolor*, *Feretia apodanthera, Ziziphus mauritiana*, the annual grass *Brachiaria lata* and forbs *Abutilon pannosum, Achyrantes aspera* (Hejcmanová et al., 2010).

Eland in intensive systems, such as that of the Czech University of Life Sciences Prague, received a mixture of roughly 60 % maize silage, 30 % lucerne silage plus small amounts of lucerne hay and barley straw (Bartoň et al., 2014). The semi-domesticated eland in Zimbabwe that were being studied by Roth and colleagues, had an average daily intake of 13.8 kg of lucerne and 2.6 kg (or 5 % of their bodyweight) of antelope concentrate cubes (Roth, 1970). These studies also reported that they spent around six to seven percent of their time grazing. At Taronga Western Plains zoo (Sydney, Australia) each individual receives a daily ration of five kilograms lucern chaff, 2.5 kg oats with available grazing and browse from *Casuarina,* *Kurrajong* and *Acacia* species. During the winter they receive an additional concentrate mix of roughly 700 g of horse pellets and 700 g of cracked lupin seeds with mineral licks.

2.3.2 **Infrastructure requirements**

Eland are well known for their extraordinary jumping ability, despite having a body that is similar in bulk to an ox (Retief, 1971). Almost all papers that have been published on eland, especially those relating to behaviour, mention their superb jumping ability and consequent problems with trying to contain these animals within a camp. The reported heights that they can jump from a standing position range from 1.5 meters to three meters for young animals (Estes & Otte, 1991; Hillman, 1979; Kingdon & Hoffmann, 2013). It is safe to assume that a 1.5 m fence can easily be cleared, whereas a 1.8-2 m fence can be jumped but often this will result in the top wires of the fence being broken (Furstenburg, 2007). Because of their enormous size and strength, combined with the jumping ability, they can also make light work of a fence that is not properly reinforced. On the other hand there are various reports and first hand experiences that suggest otherwise. Posselt noted that they lose their inclination to jump obstacles once they have been domesticated, unless they are frightened or hungry, and 5 ft. 6 in. (1.68 m) fence is high enough to contain them (Posselt, 1963). This seems to be the trend with eland that have been born in captivity and habituated successfully. At the Czech University of Life Sciences' farm, Lány, eland are bred and kept under intensive conditions without any problems, the animals that do display stressful behaviour are normally those that have been brought in from a zoo. Eland could possibly lose their inclination to jump a fence due to various reasons such as gradual loss of the ability to jump high when in captivity, the influence of dominant animals on the herd's movements, adequate nutrition removing the need to search for alternative sources, known area and thus stress from novelty, etc. Retief further argues that it is the cows who pose a strong territorial instinct often limiting the movements of the rest of the herd (Retief, 1971). He refers to a group of 20 cows that would not leave their 2300 ha camp during a disease control operation, even when parts of the fence was dropped, they refused to cross the boundary (Retief, 1971). The same group later suffered from starvation after most of their browsing was destroyed in a fire during the drought of 1970, although food was available in surrounding areas (Retief, 1971).

In the book *Intensive Wildlife Production in Southern Africa,* du Toit suggests that a fence of 2.4 meters should be high enough to keep eland inside (Du Toit, 2005). The lower part of the fence is constructed out of pre-manufactured wired fencing such as Veldspan, where predators are a problem electric wiring can be placed on the outside, and then built up to the required height with single strands of barbed wire, electric wire, etc. (Du Toit, 2005). Du Toit notes that 20-100 ha should be large enough to accommodate a breeding herd of one adult bull, one sub-adult bull and 15 cows (Du Toit, 2005). According to Furstenburg (2007), eland that do not receive supplementary feeding should not be kept in an area that is smaller than 3 000 ha. Male (N = ±20) and female eland (N = ±25) at the Czech University of Life Sciences Prague (Lány, Czech Republic) are kept seperate in a 230 m^2 barn area throughout the winter and in the summer months they have access to a 1.3 ha paddock, with additional feed provided daily. Interestingly Jakob Bro-Jørgensen (Mara Antelope Research Project and IUCN Antelope Specialist Group) and Jonathan Kingdon (zoologist and science author) both agreed that the behaviour of these confined eland (who were released on the day of their visit to the farm) kept in mixed sex and age classes similar to a wild herd structure are typically normal; showing animal personality and temperament traits that are simialr to eland that they have studied in the wild (personal communication, Antelope, Giraffe, Hippo conference Czech Republic, 19 February 2017).

2.3.3 **Natural events (migrations) involving eland**

Eland are nomadic animals with large home ranges and distinct seasonal movements (Kingdon, 1982; Pappas, 2002). These movements seem to be determined by the availability of food resources but may also have to do with mineral deficiencies which are replenished by visiting natural salines or salt licks (Pappas, 2002). Another explanation for seasonal movements could be due to the fact that there is protection in big herds, especially during the calving season, therefore smaller groups might migrate to some central area to calve within a larger herd (Furstenburg, 2007).

An example of the seasonal movements due to rainfall is the well-known Serengeti migration, which is trademarked by large numbers of wildebeest and zebra that migrate north towards the Masai Mara and back to the south of the Serengeti (Estes, 1991). Eland also form part of this migration, with numbers of around 7 000 being reported in some years (Schaller, 1972).

The herds spend most of January to March in the short-grass plains of south-eastern Serengeti, following the first rains (Holdo et al., 2009). This is also the ideal time for giving birth since the animals can regain condition lost during pregnancy and maintain milk production for their calves. From here they gradually spread west over the plains and then make their way up north to reach northern Serengeti and the Masai Mara by September (Holdo et al., 2009). By October most herds are back on their way to the south.

Another eland migration that is not as well known or documented is that of the Kgalagadi Transfrontier Park. This natural phenomenon takes places once every few years and involves eland migrating out of Botswana into the South African side of the park. It is important to note that there is considerable variance in the time between migrations and that this migration is not season specific. Micho Ferreira, section ranger in the park, reports that animals where thin during a 2007 migration and most likely looking for better food sources on the South African side, whereas they appeared to be in good condition five years later when attempting the same migration (Ferreira, 2012). In the 2012 migration more than three thousand animals were counted on the South African side, with 3 117 counted during an aerial census of the dunes. This unusually high number of eland led to over usage of watering troughs and reservoirs, placing an enormous strain on the park's water resources (Ferreira, 2012). This was exasperated further as the animals also stayed around 4 months longer compared to previous migrations, partly due to some cows giving birth during this time (Ferreira, 2012). Although it is still not known why or when this migration will take place, it can be argued that it is due to stressors in their normal home ranges forcing them to give birth elsewhere, be it due to better nutrition or some safety precaution.

2.4 Production potential of the Eland

2.4.1 **Important factors in meat production**

As mentioned by Skinner (1984), the same criteria applies when producing meat from ungulates as compared to meat production from domestic stock. These criteria include factors such as yields, chemical composition and meat quality which can either be influenced during the ante- or post-mortem periods (Issanchou, 1996)

2.4.1.1 **Ante-mortem**

Meat production potential can either be influenced by intrinsic factors such as species, sex and age (chronological and physiological maturity) or extrinsic factors such as plane of nutrition and environmental stress (von La Chevallerie et al., 1971).

2.4.1.1.1 **Intrinsic factors**

One of the major factors influencing meat quality/yield is breed/sub-species. However, unlike cattle breeds that offer a variety of different traits, the options are limited with eland since the sub-species of either species (*T. oryx* and *T. derbianus*) are only separated by phenotypic colour variances as established thus far. As mentioned before the common eland are larger in bulk which is a significant advantage in terms of meat production compared to the Derby eland. Another production management advantage the common eland has over its counterpart is that their numbers are relatively high and the species is spread over a wider variety of habitats either on game farms or in national parks, which increases the size of the available genetic pool and animals available for live sales. Therefore it is clear that the common eland have more to offer at this stage, if the number of Derby eland do not increase dramatically. Other factors, such as temperament, might differ between species but will have little influence on the meat production potential although it might have an influence on the ultimate meat quality if animals are injured during fights or stressed during the ante-mortem period. Unwanted traits like these can be selected against with the establishment of a breeding herd. Whether or not carcass changes can be achieved by means of selection will depend mainly on the heritability's of the carcass or meat characteristics in question, the ease with which they can be measured on the live animal, and the amount of genetic variability in the population of interest. For beef cattle (and other farmed livestock) the biggest challenge lies with measuring relevant characteristics in live cattle. The main options are the use of ultrasound to measure fat depths (as an indicator of carcass fat %) and eye-muscle areas (as measures of meat to bone ratio or muscularity) (Stouffer et al., 1961). Dressing-out %, carcass fat %, as well as the highest meat to bone ratio are some of the traits that are normally considered important in meat production. Although great strides have been made in genetic marker selection for specific meat quality traits in livestock, no markers have been identified yet in game meat or venison. Species type also influences other factors such as activity levels and feeding habits which have been recorded for most antelope.

The second intrinsic factor that plays a role in meat production is the sex of the animal. The animal's sex will not only influence the muscle growth or final dressing percentage but also factors linked to meat quality such as the tenderness and intermuscular fat content (Bartoň et al., 2011). Consistent patterns are not always clearly visible when comparing carcass characteristics of bulls, steers and heifers because the differences are often too small or the final live weights are not the same. When compared to cattle, eland cows and castrates have similar weight and fat deposition patterns (von La Chevallerie et al., 1971). Generally, at a set weight, heifers will be fatter than steers, and steers will be fatter than bulls. Differences in dressing-out % are less clear, but bulls usually have slightly higher values, and heifers may have higher values than steers if they are appreciably fatter (Nassu et al., 2017; Nephawe et al., 2004). Some of the fat in these steers and heifers is deposited as intramuscular fat which in turn improves tenderness as well as juiciness. Hoffman and co-workers reported that the *longissimus dorsi et lumborum* (LDL) muscle of female (2 %) eland contained more fat than that of the males (1.2 %) and females had almost double the amount of mono unsaturated fatty acids (Hoffman et al., 2015). However, it is debatable whether consumers will be able to distinguish between sexes with such low levels of intra muscular fat, this aspects warrants further research. Bulls are heavier at maturity and more muscular than cows, especially around the neck and thorax (Lawrie & Ledward, 2006b). This is also the case with eland bulls that have larger front hooves to support the enormous weight of their neck and chest. The larger muscles around the forequarters are essential for establishing dominance during fights and therefore an eland bull's neck almost doubles in circumference during the rutting season (Bro-Jørgensen & Beeston, 2015). During this time males tend to focus more on establishing dominance and mating with cows, often resulting in a loss of condition (Neethling & Hoffman, 2014; Van Zyl & Ferreira, 2004).

The third factor which will determine the quality of meat is the age or bodyweight at which the animal is slaughtered. Younger animals have a higher proportion of heat soluble collagen (Lawrie & Ledward, 2006a), whereas the number of thermally stable cross-linkages between collagen polypeptide chains are higher in older animals. These cross-linkages increase with time and have a negative influence on collagen quality, thus meat from mature animals will be tougher (Hoffman, 2001). Fat deposition mainly takes place in adult animals or when the diet is rich in energy, therefore older animals will frequently have a higher carcass fat percentage as well as more visceral and organ fat compared to juveniles. This increase in fat can be seen at intramuscular level as well, which in turn offer juicier, more flavourful meat.

2.4.1.1.2 **Extrinsic factors**

Diet quality and quantity, which is generally dependant on the season, has an influence on a few factors besides improved growth rates and protein synthesis. Ruminants are better equipped at utilising poor-quality nutrition, in comparison to single-stomached (monogastric) species. The digestive systems of game species are also better at utilising lower quality feeds (Hofmann, 1989), an important adaptation regarding the degree of difference in the quality, quantity and suitability of the vegetation available to various game species at different production regions.

Some of the meat quality attributes that have been linked to feed management strategies, certain types of feed and additives in beef, may also have a similar outcome in eland. These include meat that is more tender if an animal is fed to achieve a higher growth rate than its counterparts during the last months leading up to slaughter (Purchas & Barton, 1976); influence of grain feeding versus natural grazing on the fatty acid composition which in turn affects the flavour, similarly eland meat flavour might be affected when switching from a natural to an intensive diet (Muir et al., 1998); high levels of carotenoid pigments (particularly ß-carotene and lutein) in the diet can result in fat that has a yellow colour, which has a lower acceptance amongst consumers (Oddy et al., 2001); if the animal is malnourished (as during periods of drought or the dry months in the eland's natural habitat) leading up to slaughter there is a possibility of its muscle glycogen levels being so depleted that the ultimate pH of the meat is above normal resulting in inferior meat quality, also if this undernourishment takes place over a long period it might cause an increase in the proportion of intramuscular collagen (Lawrie & Ledward, 2006c).

Ante-slaughter handling and activity can have an effect on the ultimate pH of the meat if increased physical activity depletes glycogen levels before slaughter. The harvesting of game species is particularly stressful since their flight reaction is far more pronounced than with domestic animals and it normally results in a strenuous pursuit which does not always end with ‘n single kill shot. Game animals do not have large glycogen reserves as their diet rarely provides excess energy for storage, they can therefore only maintain short bursts of activity before tiring out. Depletion of glycogen reserves can be avoided by minimizing holding times in lairage (although this is not yet applicable in eland, it does play a role in other wild animals such as farmed deer), avoiding fasting the animals over eight hours and minimizing stressful situations (loud noise, sudden movements, overcrowding, mixing of unfamiliar animals) (Purchas et al., 2001).

The lactic acid concentration (produced from glycogen during anaerobic glycolysis) determines the ultimate pH (pHu) of the meat (Lawrie & Ledward, 2006c). Smaller muscles have higher pHu’s since their smaller muscle fibres have less glycogen reserves. They rate of glycolysis has also been recorded to be higher in muscles that cool down slower (located deeper in the carcass) (Lawrie & Ledward, 2006c). The pH_u of meat affects various qualities and attributes of the meat including its colour, flavour, tenderness, water holding capacity (WHC) and shelf-life (Honikel, 2004a). Meat with a higher pH_u has retarded oxidation of fat and myoglobin, resulting in more colour stable meat products with better flavour, however these attributes are accompanied by a decrease in the extent of post-mortem proteolysis (tougher meat products), higher WHC and higher susceptibility to bacterial spoilage (Lawrie & Ledward, 2006c; Warriss, 2000). A pH_u of over six often results in DFD (dark, firm and dry) meat and this phenomenon has been reported in a number of ungulate species when the ante mortem stress levels are too high (Hoffman & Laubscher, 2009). DFD is characterized by uneven colour development, poor processing attributes, decrease in post-mortem proteolysis which increases the toughness and water holding capacity and an overall darker colour since the muscle structure absorbs light (Hoffman, 2001; Hoffman & Laubscher, 2009; Neethling et al., 2016). The scenario can most likely be avoided once eland have been fully domesticated and habituated to human handling, since their natural behaviour is peaceful and docile. However, it has been noted that even domesticated eland stress when activities outside their normal repertoire are induced. One such activity may be the herding and loading for transport of live eland to an abattoir; it is thus recommended that eland be shot on site and the carcass transported to the abattoir for further dressing. There are numerous guidelines that help facilitate this process, particularly as found in Africa (Van Schalkwyk & Hoffman, 2016).

2.4.1.2 **Post-mortem**

Before the final product reaches the consumer a number of factors can influence the quality of that product. Some factors are intrinsic and others extrinsic, most can be controlled to a certain extent, but for a quality product to be produced, proper management is needed at all levels. A large part of this quality which will lead to consumer satisfaction can be influenced and determined in the time leading up to the eventual slaughter of the animal, but during the first 24 hours post-mortem or until rigor mortis has set in, most of the changes take place which eventually determines a successful conversion of muscle to meat (Honikel, 2004b). The most significant change of all is the ante-mortem drop in pH which normally varies between different muscles (Byrne et al., 2000). The pH_u along with the rate at which this change takes place both influence several physical characteristics of the meat, such as the colour and tenderness and water holding capacity (Honikel, 2004a). Processing facilities are not always properly equipped or up to standard resulting in different rates of pH decline and eventual meat quality, especially where refrigeration is concerned. Game carcasses are also not normally subject to electrical stimulation, which is widely used in slaughtering domestic animals and has been shown to have positive influences on rate of pH decline and tenderness (Wiklund et al., 2001).

In this early post-mortem period it is very important not to cool the carcass to a temperature below 8°C, as this might lead to cold-shortening of the muscle fibres which results in a tougher meat since the fibres are more contracted (Hoffman et al., 2009). Allowing the onset of rigor mortis to take place at a suitable temperature allows muscle fibres to release to a “relaxed” state (Pearson & Young, 1989). Various methods, such as electrical stimulation of the carcass, have been developed to accelerate the muscles to this rigor mortis phase. Afterwards the carcass can be completely frozen, but this will negatively influence the quality as well as the value of the final product, therefore carcasses are normally either stored at a low temperature if the plan is to process them quickly or in most cases they will be chilled to a temperature close to 0°C (Leygonie et al., 2012). This method has the advantage of improving tenderization due to the activity of proteolytic enzymes, but at the same time bacteria and colour changes are minimised for the first few days.

At this point in the production cycle the only intervention that can be done to change the final level of meat quality is the aging of the primal cuts to render these more tender. Besides reducing the time from the abattoir to the customer, the only other determining factor in customer satisfaction is how the final product is presented. Good presentation will be determined by the level of skill of the de-boners, appropriate packaging and post packaging treatments such as use of modified atmospheres.

Ultimately, the way in which the meat is prepared (cooked) will determine consumer satisfaction. This will differ between various cuts and muscles, but final internal temperature and time will be the main cooking variables that influence the final quality.

2.4.2 **Factors influencing consumer preference**

2.4.2.1 **Visual appearance of the meat**

Lean meat colour should not be too dark or pale, since consumers usually prefer a bright red colouring and this is the first factor they assess when determining a product's freshness (Hoffman, 2001). The most widely used objective system to asses meat colour is the CIE L*a*b* colour system (Commission International De l'Eclairage, 1976) which uses spectrophotometry to generate three values (L*, a* and b*). L* represents the light and dark scale or axis of the sample, a* represents the red and green axis where a positive value indicates a red colour and negative value a green colour, and the b* value represents the yellow and blue axis where the colour also changes from positive- yellow to negative- blue. Used together these three values represent a specific colour that can be compared anywhere in the world. Generally meat from free ranging game species would be darker in colour (lower CIE L* value) due to their higher activity level and consequently more oxidative muscle fibres (Taylor, 2004). Equally important to meat colour is the visible fat colour, which should not have a yellow colour since this is associated with lower quality or oxidation. Meat firmness is the ability of the cut to maintain its display form and is influenced by the ultimate pH, water holding capacity and fat content. Water holding capacity is the ability of a piece of meat to retain moisture when a force is being applied on it. A lower WHC causes water to be exuded from the intermolecular spaces to form drip on the surface of the meat, this will decrease the weight of the product and has a less appealing appearance. Besides that the meat might be perceived as dry after it's been cooked (Warriss, 2000). In terms of composition most consumers prefer a cut with less fat, except for certain cuts where marbling might be preferred. The same goes for the meat to bone ratio of the cut.

2.4.2.2 **Tenderness**

Tender meat is favoured in western diets and is in most cases the feature of beef that customers are most often dissatisfied with. The tenderness of skeletal muscles can be influenced by cold shortening of muscle fibres, the type and amount of connective tissue as well as the enzymes that are involved post-mortem and, to a certain degree, the intramuscular fat and moisture content (Swartland, 1994). Furthermore muscle fibre type and collagen composition varies between different skeletal muscles according to their placement and level of activity, which will influence their tenderness (Lawrie & Ledward, 2006c).

2.4.2.3 **Flavour**

Flavour preference varies widely among people, because of their cultural background and past experiences. Odour differences are more often picked up than flavour differences and could therefore influence the consumer's choice. Meat shouldn't be dry and firm, but rather juicy and tender. Juiciness is influenced by both the moisture content of the meat as well as the intramuscular fat content as this stimulates saliva production in the mouth (Jeremiah et al., 2003). An important factor that is largely responsible for influencing the flavour is the fatty acid composition of the meat (Wood et al., 2008). More specifically the production of volatile, odorous, lipid oxidation products and their reaction with Maillard reaction products during the cooking of the fatty acids. Fat content itself affects the flavour and aroma, since the triacylglycerols in the fatty acid composition of the total lipid is more saturated than phospholipids in the muscle membranes, and with increased fatness the triacylglycerols will increase (Wood, Enser, Fisher, et al., 2008). Cameron and Enser (1991) found that saturated and mono-unsaturated fatty acids (MUFA) were positively associated with eating quality traits, while negative correlations with eating quality were made with polyunsaturated fatty acids (PUFA).

2.4.2.4 **Nutritional value**

Lean beef is considered a high quality, concentrated source of easily digestible nutrients, because it has a high protein to energy ratio and the protein is of high quality. Red meat is an excellent source of zinc, iron and B vitamins, especially B12. Meat is made up out of five chemical constituents namely moisture (± 75-80 g/100 g), proteins (± 18-25 g/100 g); IMF (± 1-13 g/100 g); carbohydrates (± 1-2 g/100 g of glycogen) and ash (± 1 g/100 g). Game meat has higher protein content as well as significantly lower quantities of fat and energy (kJ) compared to meat from domesticated livestock (Hoffman & Cawthorn, 2013). The protein content of game meat is generally > 20 g/100 g and the IMF content < 3 g/100 g (Aidoo & Haworth, 1995; D. L. Van Schalkwyk & Hoffman, 2016). As mentioned, the fatty acid content not only influences the flavour and aroma of the meat, but can also have a positive or negative impact on human health if the composition of fatty acids are unfavourable. The muscle content of phospholipids is relatively constant and contains mainly PUFA, while the neutral lipids in the muscle, which mainly consist of SFA and MUFA, increase as the intramuscular fat content increases. When considering the nutritional value of meat that contains fat there are three interrelated factors that are important: the total fat content, the poly-unsaturated to saturated fatty acid ratio (P:S) and the omega-6 to omega-3 fatty acid ratio (ω6:ω3/ n-6:n-3) (Cordain et al., 2002; Wood et al., 2008). High levels of PUFA's have been recorded for various game species as well as high P:S and low n-6:n-3 ratios (Hoffman & Wiklund, 2006).

In recent years there has been a positive shift in the market towards organically produced or "free range" products, which is believed to be healthier because of the way it produced and it is guaranteed to be free from any growth stimulants, chemicals or hormones while having a less negative impact on the environment. Game meat can potentially be marketed under the same label, since most animals are free-roaming and consume an organic diet (Hoffman & Wiklund, 2006). Game meat can also be considered healthier than other red meats (Bartoň et al., 2014), because of the low intramuscular fat content (Hoffman & Wiklund, 2006) as well as a more desirable essential fatty acid profile (Cordain et al., 2002).

2.4.3 **What we know of eland production and meat yields**

As mentioned earlier, eland have long been prized for their high quality meat, which is considered as one of the best game meats because of the higher fat content and thus improved flavour and juiciness. However most of this prized meat has in the past been harvested by biltong hunters on game ranches and was rarely the product of intensive production (NAMC, 2006). In the same breath, meat production and domestication attempts with the eland did not seem to gain popularity with farmers after the research that was done in the 60's and 70's (Carruthers, 2008). This, in part, may be due to the fact that most of South Africa's meat consumers are not accustomed to game meat. Since it is hard to come by on the local market, more expensive than commercially produced meat or the knowledge of preparation/cooking is lacking.

2.4.3.1 **Eland production**

John Posselt was one of the first farmers to truly pursue eland domestication and was able to make a few detailed observations of his herd of 24 animals at Zezani, Beit Bridge (Posselt, 1963). Among these observations were the live weights at different intervals and up to six years for certain animals, calving intervals and other reproductive traits. His youngest animal accepted a bull by the age of 18 months, although most only conceived a year later, and oestrus occurred at intervals of 21 to 26 days (Skinner, 1966). Interestingly in his bodyweight data of the males, the castrates were heavier than the non-castrated animals up to the age of four years when the non-castrates caught up in weight (Posselt, 1963).

Skinner (1966), Treus and Lobanov (1971) made a few comparisons between eland from the Askanya Nova institute and eland that were produced locally at the time. Skinner noted that eland in the Ukraine have a slightly longer gestation period of 276 days, but the birthweights of 34.9 kg and 27.9 kg for males and females, respectively, seemed to be in line with what Posselt recorded for his herd (in southern Africa). He also compared these birthweights along with the calving percentages and intercalving periods with those of Afrikaner cattle and concluded that eland might have equivalent or even better reproductive performance, but these reproductive traits needed further comparison in the same habitat under the same nutritional conditions (Skinner, 1966). Skinner also commented on the eland of Askanya Nova requiring between 30-40 % more total digestible nutrients per unit of growth than Afrikaner cattle of similar age (Skinner, 1966). Lightfoot (1977) commented that this is most likely due to the differences in ambient temperature, however Kotrba and colleagues reported that eland were able to minimize body heat loss by lowering their surface temperature (Kotrba et al., 2007). According to Skinner (1966), cross breeding attempts with cattle have been unsuccessful in the past and those attempts that were deemed successful were later proved to be cattle, since the embryo dies early in its development phase. Treus and Lobanov (1971) reported in detail about the genealogy of the Askanya Nova eland, their reproductive performance and offspring as well as the yields for the herd of milking cows. They stressed the importance of maintaining genetic variance with "new blood" since they only acquired one new sire in the 60 year period after the first eland were imported in 1892, resulting in new-borns with deformed limbs and skeletons (Treus & Lobanov, 1971).

In 1971 von La Chevallerie and colleagues compared carcass data of six free range bulls from the S.A. Lombard Nature reserve, without supplementary feeding, to three castrates that were used in metabolism studies at Onderstepoort (von La Chevallerie et al., 1971). These studies were conducted by two different research teams with different methods of measuring, moreover the sample groups were too small to make any definite conclusions or meaningful comparisons. The average weight of the castrates was 412.7 kg and 408.5 kg for the free range bulls, however their ages ranged between 3.5 and 10 years (von La Chevallerie et al., 1971). It is interesting to note that the low fat content of an eland's carcass could be raised by castrating males and finishing them on high quality feed. The castrates had a fat percentage of 12.1 % (3-rib-cut used) compared to only 2.4 % (buttock used) for the six bulls (von La Chevallerie et al., 1971).

Lightfoot (1977) reported that eland had a higher calving percentage than cattle, but this seems to be overshadowed by high calf mortalities. Referring to the eland at Manyoli, he noted that these mortalities in the young calves were one of the biggest challenges regarding eland production, but with the help of long term selective breeding it might be overcome (Lightfoot, 1977).

Jeffery and Hanks (1981) investigated the post-natal growth in live mass and body dimensions of a herd of captive eland in the Drakensberg Mountains in Natal, by using von Bertalanffy growth equations. Asymptotic live mass of males (575 kg) was 45 % higher than that of females (316 kg) and body dimensions also showed clear differences between sexes (Jeffery & Hanks, 1981). Furthermore they compared the male and female birth weights and growth rates of the Cape eland in their trial to the Livingstone eland of Posselt and in both instances the Livingstone's did better. However it should be noted that these two populations occurred in completely different habitats (Zimbabwean bushveld and Natal highveld) with different management strategies, therefore it is not clear whether the growth differences are phenotypic or genotypic.

As mentioned in section 2.3.2, eland have been farmed in Lány, near Prague (Czech Republic) since 2006. During this time data has been collected on the herd and used in a few studies. One study looked at the endocrinology of pregnant and post-partem eland cows (aged between 3-11 years, live weight of 285-406 kg) (Hubmer, 2011). A gestation period of 251-264 days was reported, with calf weights of 31.3 kg and 28.0 kg for males and females respectively.

2.4.3.2 **Previous comparisons between eland and beef**

When compared to cattle, there are a number of factors that give eland an advantage when the two are placed together in a challenging environment. The first advantage is their resistance to parasites and disease, for example the "Nagana" disease which is transmitted by tsetse flies (Lambrecht, 1983). Eland have also shown to have a significant tolerance when it comes to diets that have higher tannins and toxins (Retief, 1971). Where cattle would only graze on familiar species of plants and leave weeds to grow, eland will level the whole pasture to the same height (Hofmeyer, 1970). On the same note, eland are intermediate feeders, indicating that they are not only able to ingest browse, but also grasses, making them better adapted to thrive in natural areas which would otherwise have to be converted into better pastures to suit cattle (Watson & Owen-Smith, 2000). The fact that eland need a larger area to meet their feeding habits only apply to eland that are receiving no supplementary feeding, therefore eland can be kept in the same size camp as cattle, given they receive adequate feed. Eland are also known to be independent on water since they can draw enough moisture from the natural vegetation enabling them to browse a much larger area than cattle in arid or semi-arid extensive systems, however in an intensive sysetm with produced feed they will need regular access to water (Taylor & Lyman, 1967). This is especially significant since the Intergovernmental Panel on Climate Change (IPCC) projects that Sub-Saharan Africa is likely to experience a greater increase in temperatures along with decreasing rainfall in certain regions (IPCC, 2007).

There is no doubt that the eland is the closest comparable wild animal to beef. This has also been the focus point of various studies, investigating the similarities and potential for substitution. These studies focused on the reproductive performance as well as the meat characteristics of the eland.

In 1967, Taylor and Lyman studied the physiological adaptations and water requirements of eland compared to Hereford cattle. They found that although eland might be better adapted to arid regions than cattle, they fall short in productivity because their high metabolic rate and narrow thermal neutral zone demand a higher feed intake per weight of meat produced. They also reported higher urea excretion in the eland, which would indicate that the eland is not as effective in absorbing protein from feed (Taylor & Lyman, 1967).

One of the more recent studies by Bartoň and colleagues (2014), compared physical characteristics, chemical composition, and sensory characteristics of meat from Fleckvieh (*Bos taurus*) cattle and eland finished under controlled conditions of feeding and management. The *Longissimus thoracis et lumborum* (LTL) muscle was analysed and the pH_{24} was higher in eland than in cattle, but only one animal had a pH higher than 5.8 (Bartoň et al., 2014), which is still well under the point where meat quality starts to degrade (Mach et al., 2008). Eland also had significantly darker, but less yellow colouring of the LTL (Bartoň et al., 2014). In terms of chemical composition the eland had less intramuscular fat and collagen, but no significant differences were found in the protein or cholesterol levels of the two species (Bartoň et al., 2014). In cattle, the contents (mg/100 g muscle tissue) and proportions (g/100 g of fatty acids determined) of SFA and MUFA were higher, while the PUFA composition were similar between species, although eland had higher proportion of PUFA (Bartoň et al., 2014). The PUFA/SFA ratio of eland was more than double that of cattle and also exceeded the minimum ratio of 0.4, which is considered to reduce the risk of coronary disease in humans (Wood, Enser, Richardson, & Whittington, 2008). For the sensory analysis, meat from both species was aged under refrigerated (4 °C) conditions for either three or 14 days. Eland meat (steaks grilled to 70°C in core) was consistently scored lower for texture, flavour intensity and overall acceptance for both of the aging periods (Bartoň et al., 2014). It is interesting to note that for both species, aging improved all the sensory characteristics, except for the odour intensity (Bartoň et al., 2014).

2.4.3.3 **Eland milk**

At Askanya Nova, efforts to milk eland started as early as 1950, with the establishment of a herd of 21 milking cows over the 14 year period that followed (Treus & Lobanov, 1971). The eland at Askanya were subject to a gradual learning routine where they would be tethered and then their udders would be stimulated by massaging (Treus & Kravchenko, 1968). This seemed to be a recipe for success since the animals showed no objective to being milked in the years that followed (Treus & Kravchenko, 1968). The highest yielding animal and oldest of the herd produced seven litres a day, with a total of 637 litres in her 7th lactation. Treus and Kavchenko (1971) reports that eland milk has a higher fat (9.1 to 12.6 %) and albumin (6.9 to 8.7 %) percentage than that of cattle, and according to their analysis the dry matter (21.97 to 23.53 %) and protein (5.9 to 9.7 %) content was almost double that of cattle milk. The lactose (3.6 to 4.2 %) and non-protein nitrogen (0.25 %) content was similar to that in cow’s milk, but calcium and phosphorus contents from some animals were reported to be as high as three times the amount for dairy cows (Treus & Lobanov, 1971). The chemical composition of the milk throughout the lactation period was monitored and the fat, mineral and casein percentages were found to increase with lactation time. It was noted however, that for some individuals these percentages would change dramatically in a short period, as for one cow whose fat percentage increased from nine to 15 % in less than 62 days, and that these cases would be subject to selection breeding for the years to come in an effort to improve yields (Treus & Lobanov, 1971). Unfortunately, no further work has been published to indicate whether this selection had indeed occurred.

Due to the eland milk’s bacterial properties and superior shelf life of up to three months, it was also used as clinical treatment for stomach and duodenal injuries or ulcers (Treus & Kravchenko, 1968). Supposedly chronic patients benefited markedly from a 10-21 day course of eland milk. This success was ascribed to either the high protein content or the presence of biogenic factors and the milk was reported to lower the hyperacidity of stomach juice, thus helping with the recovery of ulcers (Treus & Kravchenko, 1968).

Posselt (1963) had two of his cows' milk tested at the University College of Rhodesia and the result fell in the same ranges as was established at Askanya Nova. Both samples had a fat content of 11 % and protein content of 8.2 %, and lactose of 4 and 4.5 %, respectively. The milk was characterized by a low amount of volatile fatty acids and a higher content of palmitic acid than other milk fats, therefore it had a better butter yield and a high softening point (Posselt, 1963). Posselt reported that roughly two quarts can be expected in the morning from a cow that has been separated from her calf in the night.

Van Zyl and Wehmeyer (1970) from the S.A. Lombard Nature Reserve, were assigned with the task of establishing the composition of springbok, black wildebeest and eland milk so that the calves of the separate species could be fed with specific diets to avoid diarrhea. One eland was milked for testing and mostly fed on lucern, maize meal and grass hay and was supplemented with a mineral lick. First of all the cow's colostrum was tested and showed high contents of protein (15 g/100 g), fat (10 g/100 g), calcium (221 mg/100 g) and phosphorus (176 mg/100 g). After the colostrum period the protein content dropped to between 7.2 and 8 g/100 g, the fat content remained roughly the same, but the lactose content increased from 3.9 to 4.9 g/100 g (Van Zyl & Wehmeyer, 1970).

2.5 Conclusions

Historically eland have played an important role in the game industry of South Africa, especially during the days of the hunter-gatherer communities and early settlers, however consumers in this day and age are not as familiar with this lean, healthy meat as it is not widely available for hunting, considerably more expensive per animal than smaller game and the meat is rarely available at butcheries or supermarkets. Needless to say, there has been limited data published on the meat quality and characteristics of this animal, although studies in the past have investigated production and domestication potential. Furthermore studies on the nutritional value and meat quality of eland is mainly limited to the *Longissimus dorsi muscle* (loin) (Bartoň et al., 2014; Hoffman et al., 2015), since the meat industry regards this muscle as the most representable of the total carcass composition and quality (Warriss, 2000). Only one of these studies included female animals as well as males.

Meat is an important part of our daily food intake and game animals are as synonymous with South Africa as is Nelson Mandela. Meat scientists should have a thorough knowledge of its composition, nutritive value, quality, storage life and physical properties in order to advise farmers, retailers and consumers about specific aspects relating to meat quality and healthiness. It is evident from this literature review that there are still many aspects of eland meat that need to be investigated. Although studies have been done on all the factors and properties affecting the sensory, physical and chemical properties of meat from domestic species, there is a definite lack of proven scientific research on South African wild ungulates and game species. The limited research available indicates that there are positive health influences when consuming game meat alongside other benefits such as better adaptability and less management and input costs. These advantages need to be investigated and highlighted for individual species so as to aid in the marketing and growth of the game meat industry as a whole.

2.6 References

Aidoo, K. E., & Haworth, R. J. (1995). Nutritional and chemical composition of farmed venison. *Journal of Human Nutrition and Dietetics*, 8, 441–446.

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. *Meat Science*, 96, 346–352.

Bartoň, L., Bureš, D., Kott, T., & Řehák, D. (2011). Effect of sex and age on bovine muscle and adipose fatty acid composition and stearoyl-CoA desaturase mRNA expression. *Meat Science*, 89, 444–450.

Blyth, E. (1863). Catalog of Mammalia in the museum of the Asiatic Society of Bengal. *The Asiatic Society.*

Bro-Jørgensen, J. (1997). The ecology and behaviour of the Giant Eland (*Tragelaphus derbianus*, Gray 1847) in the wild. Master's tesis, University of Copenhagen.

Bro-Jørgensen, J., & Beeston, J. (2015). Multimodal signalling in an antelope: Fluctuating facemasks and knee-clicks reveal the social status of eland bulls. *Animal Behaviour*, 102, 231–239.

Brown, K. (2005). Tropical medicine and animal diseases: Onderstepoort and the development of veterinary science in South Africa 1908-1950. *Journal of Southern African Studies*, 31, 513–529.

Brown, K., & Gilfoyle, D. (2007). Introduction: livestock diseases and veterinary science in Southern Africa. *South African Historical Journal*, 58, 2–16.

Byrne, C. E., Troy, D. J., & Buckley, D. J. (2000). Postmortem changes in muscle electrical properties of bovine *M. longissimus dorsi* and their relationship to meat quality attributes and pH fall. *Meat Science*, 54, 23–34.

Cameron, N. D., & Enser, M. B. (1991). Fatty acid composition of lipid in *longissimus dorsi* muscle of Duroc and British Landrace pigs and its relationship with eating quality. *Meat Science*, 29, 295–307.

Carruthers, J. (2008). "Wilding the farm or farming the wild"? The evolution of scientific game ranching in South Africa from the 1960s to the present. *Transactions of the Royal Society of South Africa*, 63, 160–181.

Castelló, J. R. (2016). Bovids of the world. Oxford: Princeton University Press.

Cordain, L., Watkins, B. A, Florant, G. L., Kelher, M., Rogers, L., & Li, Y. (2002). Fatty acid analysis of wild ruminant tissues: evolutionary implications for reducing diet-related chronic disease. *European Journal of Clinical Nutrition*, 56, 181–191.

Darroze S. (2004). Western Giant Elend (*Tragelaphus derbianus derbianus*) presence confirmed in Mali and Guinea. *Antelope Survey Update*, 9, 21 – 23.

Davies, G., & Brown, D. (2008). *Bushmeat and livelyhoods: wildlife management and poverty reduction*. New Jersey: John Wiley & Sons.

De Blaineville, H. M. D. (1816). *Bulletin des Sciences, par la Société Philomatique*. Paris.

Du Toit, J. G. (2005). The eland in *Intensive Wildlife Production in Southern Africa*. In J. D. P. Bothma & N. Van Rooyen (Eds.). Pretoria: Van Schaik Publishers.

Estes, R. D. (1991). *The behaviour guide to African mammals : including hoofed mammals, carnivores, primates*. California: University of California Press

Ferreira, M. (2012). Impact of Eland on water resources within the Kgalagadi Transfrontier Park. *San Parks Times*, 52.

Flack, P. (2013). *Hunting the Spiral Horns: Eland, Everyman's Elephant*. Johannesburg: Rowland Ward Publications.

Furstenburg, D. (2007). Eland *Tragelaphus oryx*. Game & Hunt, 6–11.

Gentry, A. W. (1978). Bovidae. In V. J. Maglio & H. B. S. Cooker (Eds.), *Evolution of African* Mammals (pp. 540–572). Cambridge: Harvard University Press.

Harper, D. (2001). Taurus. Retrieved February 24, 2017, from http://www.etymonline.com/index.php?term=taurus

Hejcmanová, P., Homolka, M., Antonínová, M., Hejcman, M., & Podhájecká, V. (2010). Diet composition of Western Derby eland (*Taurotragus Derbianus Derbianus*) in the dry season in a natural and a managed habitat in Senegal using faecal analyses. *South African Journal of Wildlife Research*, 40, 27–34.

Hillman, J. C. (1979). The biology of the eland (*Taurotragus oryx*) in the wild. Doctoral dissertation, University of Nairobi.

Hillman, J. C. (1988). Home range and movement of the common eland (*Taurotragus oryx* Pallas 1766) in Kenya. *African Journal of Ecology*, 26, 135–148.

Hoffman, L. C. (2001). The effect of different culling methodologies on the physical meat quality attributes of various game species. In H. Ebedes, B. Reily, W. Van Hoven, & B. Penzhorn (Eds.), Proceedings of the 5th International Wildlife Ranching Symposium Sustainable Utilization - Conservation in practice (pp. 212–221). Pretoria, South Africa.

Hoffman, L. C., & Cawthorn, D. (2013). Exotic protein sources to meet all needs. *Meat Science*, 95, 764–771.

Hoffman, L. C., & Laubscher, L. L. (2009). The effect of different cropping methods on the meat quality of various game species. Doctoral dissertation, University of Stellenbosch.

Hoffman, L. C., Van Schalkwyk, D., McMillin, K. W., & Kotrba, R. (2015). Intramuscular fat characteristics of Namibian common eland (*Tragelaphus oryx*). *African Journal of Wildlife Research*, 45, 312–320.

Hoffman, L. C., van Schalkwyk, S., & Muller, N. (2009). Effect of season and gender on the physical and chemical composition of black wildebeest (*Connochaetus gnou*) meat. *South African Journal of Wildlife Research*, 39, 170–174.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, 74, 197–208.

Hofmann R.R. (1989). Evolutionary Steps of Ecophysiological Adaptation and Diversification of Ruminants: A Comparative View of Their Digestive System. *Oecologia*, 78, 443–457.

Hofmeyer, J. M. (1970). A review of the food preferences and feeding habits of some indigenous herbivores in the Ethiopian faunal region and some studies on animal plant relationships. In proceedings of the *South African Society of Animal Production*, 9, 89–99.

Holdo, R. M., Holt, R. D., & Fryxell, J. M. (2009). Opposing rainfall and plant nutritional gradients best explain the wildebeest migration in the Serengeti. *The American Naturalist*, 173, 431–45.

Honikel, K. O. (2004a). Chemical and physical characteristics of meat/pH measurement. (W. K. Jensen, C. Devine, & M. Dikeman, Eds.). Oxford: Elsevier Academic Press.

Honikel, K. O. (2004b). Conversion of muscle to meat/ Glycolysis. In W. K. Jensen, C. Devine, & M. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 314–318). Oxford: Elsevier Academic Press.

Hubmer, I. (2011). Rank of female and sex of fetus influence reproductive endocrinology of pregnant and post-partum elands (*Taurotragus oryx*) in captivity. Doctoral dissertation, University of Veterinary Medicine, Vienna.

Lemke, P., Ren, R., & Alley, I. (2007). The physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Climate Change 2007*, 337-383.

Issanchou, S. (1996). Consumer expectations of meat and meat product quality. *Meat Science*, 43, 5-19.

IUCN SSC Antelope Specialist Group. (2008). *Tragelaphus derbianus*. The IUCN Red List of Threatened Species.

Jeffery, R. C. V., & Hanks, J. (1981a). Age determination of eland *Taurotragus oryx* (Pallas, 1766) in the Natal Highveld. *South African Journal of Zoology*, 16, 113.

Jeffery, R. C. V., & Hanks, J. (1981b). Body growth of captive eland *Taurotragus oryx* in Natal. *South African Journal of Zoology*, 16, 183–189.

Jeremiah, L. E., Dugan, M. E. R., Aalhus, J. L., & Gibson, L. L. (2003). Assessment of the relationship between chemical components and palatability of major beef muscles and muscle groups. *Meat Science*, 65, 1013–1019.

Kingdon, J. (1982). *East African mammals : an atlas of evolution in Africa*. London: Academic Press.

Kingdon, J. (1997). *The Kingdon field guide to African mammals*. London: Academic Press

Kingdon, J., & Hoffmann, M. (2013). *Tragelaphus oryx*. In *The Mammals of Africa* (pp. 126–141). London: Academic Press.

Kotrba, R., Knížková, I., Kunc, P., & Bartoš, L. (2007). Comparison between the coat temperature of the eland and dairy cattle by infrared thermography. *Journal of Thermal Biology*, 32, 355–359.

Commission International de L'Eclairage. (1976). Colorimetry (2nd ed.). Vienna: CIE.

Lambrecht, F. L. (1983). Game Animals: A Substitute for Cattle? *Rangelands Archives*, *5*, 22-24.

Lawrie, R. A., & Ledward, D. A. (2006a). Chemical and biochemical constitution of muscle. In *Lawrie's Meat Science* (pp. 75–127). Cambridge: Woodhead Publishing Limited.

Lawrie, R. A., & Ledward, D. A. (2006b). Factors influencing the growth and development of meat animals. In Lawrie's Meat Science (pp. 15–40). Cambridge: Woodhead Publishing Limited.

Lawrie, R. A., & Ledward, D. A. (2006c). The conversion of muscle to meat. In Lawrie's Meat Science (pp. 128–156). Cambridge: Woodhead Publishing Limited.

Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, 91, 93–98.

Lightfoot, C. R. (1977). Eland (*Taurotragus oryx*) as a ranching animal complementary to cattle in Rhodesia. *Rhodesia Agricultural Journal*, 74, 47–120.

Lyell, D. D. (2016). *Memories of an African Hunter* (The Peter Capstick Library). (P. Capstick, Ed.). New York: St. Martin's Press.

Mach, N., Bach, A., Velarde, A., & Devant, M. (2008). Association between animal transportation, slaughterhouse practices, and meat pH in beef. *Meat Science*, 78, 232–238.

Methuen, H. H. (1848). *Life in the wilderness: or, wanderings in South Africa.* London: Richard Bentley.

Moe, H. (1953). Letter to editor*. African Wildlife*, 7, 68–69.

Mossman, S. L., & Mossman, A. S. (1976). Wildlife utilization and game ranching: Report on a study of recent progress in this field in Southern Africa. International Union for Conservation of Nature and Natural Resources occassional paper no. 17. Morges, Switzerland.

Muir, P. D., Deaker, J. M., & Bown, M. D. (1998). Effects of forage- and grainbased feeding systems on beef quality: A review. *New Zealand Journal of Agricultural Research*, 41, 623–635.

NAMC. (2006). Report on the Investigation to Identify Problems for Sustainable Growth and Development in South African Wildlife Ranching. Pretoria, South Africa.

Nassu, R. T., Tullio, R. R., Berndt, A., Francisco, V. C., Diesel, T. A. & Alencar, M. M. (2017). Effect of the genetic group, production system and sex on the meat quality and sensory traits of beef from crossbred animals. *Tropical Animal Health and Production*, 49, 1289–1294.

Neethling, J., Hoffman, L. C., Britz, T. J. (2014). Impact of season on the chemical composition of male and female blesbok (*Damaliscus pygargus phillipsi*) muscles. *Journal of the Science of Food and Agriculture, 94, 424-431.*

Neethling, N. E., Hoffman, L.C., & Suman, S. P. (2016). Color stability of three blesbok (*Damaliscus pygargus phillipsi*) muscles. *Meat Science*, 112, 133.

Nell, D. D. (2003). The development of wildlife utilisation in South Africa and Kenya c. 1950-1990. Unpublished doctoral thesis. University of Oxford.

Nephawe, K. A., Cundiff, L. V., Dikeman, M. E., Crouses, J. D., & Van Vleck, L. D. (2004). Genetic relationships between sex-specific traits in beef cattle: Mature weight, weight adjusted for body condition score, height and body condition score of cows, and carcass traits of their steer relatives. *Journal of Animal Science*, 82, 647-653.

Nežerková, P., Verner, P., & Antonínová, M. (2004). The conservation programme of the western giant eland (*Taurotragus derbianus derbianus*) in Senegal–Czech Aid Development Project. *Gazella Zoo Praha*, 31, 87–182.

Oddy, V. H., Harper, G. S., Greenwood, P. L., & McDonagh, M. B. (2001). Nutritional and developmental effects on the intrinsic properties of muscles as they relate to the eating quality of beef. Australian Journal of Experimental Agriculture, 41, 921–942.

Pappas, L. A. (2002). *Taurotragus oryx*. *Mammal Species*, 689, 1–5.

Patterson, C. & Khosa, P. (2005) Background research paper: A status quo study on the professional and recreational hunting industry in South Africa. TRAFFIC. October, 2005 http://www.traffic.org/general-topics.html, Accessed August, 2017.

Pearson, A. M., & Young, R. B. (1989). Post-mortem changes during conversion of muscle to meat. In *Muscle and Meat Biochemistry* (pp. 391–444). Cambridge: Academic Press.

Posselt, J. (1963). The domestication of the eland. *Rhodesian Journal of Agricultural Research*, 1, 81-87.

Purchas, R. W., & Barton, R. A. (1976). The tenderness of meat of several breeds of cattle raised under New Zealand pastoral conditions. *New Zealand Journal of Agricultural Research*, 19, 421–428.

Purchas, R. W., Burnham, D. L., & Morris, S. T. (2001). On-farm and preslaughter treatment effects on beef tenderness. Institute of Food, Nutrition and Human Health, Massey University, Palmerston North.

Retief, G. P. (1971). The potential of game domestication in Africa, with special reference to Botswana. *Journal of the South African Veterinary Association*, 42, 119–127.

Ropiquet, A. (2006). Etude des radiations adaptatives au sein des Antilopinae (Mammalia, Bovidae). Doctoral Dissertation, University of Paris VI (Pierre et Marie Curie).

Roth, H. H., Kerr, M. A., & Posselt, J. (1972). Studies on the utilization of semi-domesticated eland (*Taurotragus oryx*) in Rhodesia. 2 - Feeding habits and food preferences. *Rhodesian Journal of Agricultural Research*, 8, 71–77.

Schaller, G. B. (2009). The Serengeti lion: a study of predator-prey relations. Chicago: University of Chicago Press.

Skinner, J. D. (1966). An appraisal of the eland (*Taurotragus oryx*) for diversifying and improving animal production in South Africa. *African Wild Life*, 20, 29–40.

Skinner, J. D. (1967). An appraisel of the eland as farm animal in Africa. *Animal Breeding Abstracts*, 35, 177–186.

Skinner, J. D. (1971). Productivity of the eland: an appraisal of the last five years' research. *South African Journal of Science*, Desember, 534–539.

Skinner, J. D. (1984). Selected species of ungulates for game farming in Southern Africa. *Acta Zoologica Fennica*, 172, 219-220.

Spinage, C. A. (1986). *The Natural History of Antelopes*. London: Croom Helm.

Stouffer, J. R., Wallentine, M. V., Wellington, G., & Diekmann, A. (1961). Development and application of ultrasonic methods for measuring fat thickness and rib-eye area in cattle and hogs. *Journal of Animal Science*, *20*, 759-767.

Swartland, H. J. (1994). The conversion of muscles to meat. In *Structure and Development of Meat Animals and Poultry* (pp. 495–581). Pennsylvania: Technomic Publishing Company, Inc.

Talbot, L. M., Payne, W. J. A., Ledger, H. P., Verdcourt, L. D., & Talbot, M. H. (1965). The meat production potential of wild animals in Africa: a review of biological knowledge. Technical Communication No. 16. Edinburgh.

Taylor, C. R., & Lyman, C. P. (1967). A comparative study of the environmental physiology of an east African antelope, the eland, and the Hereford steer. *Physiological Zoology*, 40, 280-295.

Taylor, R. G. (2004). Muscle fiber types and meat quality. In W. K. Jensen, C. Devine, & M. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 876–882). Oxford: Elsevier/Academic Press.

Treus, V. D., & Kravchenko, D. (1968). Methods of rearing and economic utilization of eland in the Askanya-Nova Zoological Park. *The Zoological Society of London*, 21, 395–411.

Treus, V. D., & Lobanov, N. V. (1971). Acclimatisation and Domestication of the Eland at Askanya-Nova Zoo. *International Zoo Yearbook*, 11, 147–156.

Van der Merwe, P. J. (1995). The migrant farmer in the history of the Cape colony, 1657-1842 (Translated by Roger B. Beck). Athens: Ohio University Press.

Van der Merwe, P., & Saayman, M. (2004). *Managing Game Farms from a Tourism Perspective* Potchefstroom, University of the North West: Institute for Tourism and Leisure Studies.

Van Schalkwyk, D. L., & Hoffman, L. C. (2016). *Guidelines for the harvesting & processing of wild game in Namibia*. Republic of Namibia, Ministry of Environment & Tourism.

Van Zyl, J. (2000, October). Wildplase verg slimmer planne. *Finansies & Tegniek*.

Van Zyl, J. H. M. (1965). The vegetation of the S. A. Lombard Nature Reserve and its utilisation by certain antelop. *Zoologica Africana*, 1, 55–71.

Van Zyl, J. H. M., & Wehmeyer, A. S. (1970). The composition of the milk of springbok (*Antidorcas marsupialis*), eland (*Taurotragus oryx*) and black wildebeest (*Connochaetes gnou*). *Zoologica Africana*, 5, 131–133.

Van Zyl, L., & Ferreira, A. V. (2004). Physical and chemical carcass composition of springbok (*Antidorcas marsupialis*), blesbok (*Damaliscus dorcas phillipsi*) and impala (*Aepyceros melampus*). *Small Ruminant Research*, 53, 103–109.

Von La Chevallerie, M., Erasmus, J. M., Skinner, J. D., & Van Zyl, J. H. M. (1971). A note on the carcass composition of the common eland (*Taurotragus oryx*). *South African Journal of Animal Sciences*, 1, 129–131.

Warriss, P. D. (2000). *Meat Science: An introductory text*. Wallingford: CAB International Publishing.

Watson, L. H., & Owen-Smith, N. (2000). Diet composition and habitat selection of eland in semi-arid shrubland. *African Journal of Ecology*, 38, 130–137.

Wilson, D. E., & Reeder, D. M. (2005). *Mammal species of the world : a taxonomic and geographic reference*. Baltimore: Johns Hopkins University Press.

Wilson, V. J. (1969). Eland, *Taurotragus oryx*, in eastern Zambia. Arnoldia (National Museums of Southern Rhodesia), 4, 1–9.

Wood, J. D., Enser, M., Fisher, A. V., Nute, G. R., Sheard, P. R., Richardson, R. I., Whittington, F. M. (2008). Fat deposition, fatty acid composition and meat quality: A review. *Meat Science*, 78, 343–358.

Wood, J. D., Enser, M., Richardson, M., & Whittington, F. M. (2008). Fatty acids in meat and meat products. In C. K. E. Chow (Ed.), *Fatty acids in foods and their health implications*. New York: Taylor & Francis Group.

Worthington, E. B. (1938). Science in Africa: A review of scientific research relating to Tropical and Southern Africa. London: Oxford University Press.

Chapter 3: The carcass yields and composition of eland (*Tragelaphus oryx*)

3.1 Abstract

Eland were harvested on a farm outside Bredasdorp in the Western Cape. Females (n=6) had a mean live weight of 357.2 kg and males (n=6) 305.4 kg, with cold carcass weights of 162.4 kg and 153.8 kg, respectively. Dressing percentages were calculated from the warm carcass weight and was similar for females and males (48.6 % and 50.8 %, respectively). Seven muscles were removed from the quarters and their weights recorded. The muscles that were removed included the *M. infraspinatus* (IS), *M. supraspinatus* (SS), *M. longissimus thoracis et lumborum* (LTL), *M. psoas major* (PM), *M. biceps femoris* (BF), *M. semimembranosus* (SM), *M. semitendinosus* (ST). The LTL (3.99-4.21 kg), BF (3.27-4.04 kg) and SM (3.39-3.75 kg) were the heaviest of the seven muscles removed from the carcass and was on average three to four times the size of the IS (1.15-1.32 kg), SS (0.86-1.15 kg), PS (0.99-1.22 kg) and ST (1.33-1.60 kg). Furthermore eland offer a significant portion (around 26 % of the warm carcass weight, excluding the head) of edible offal due to their large size. Eland have the potential to yield significant amounts of game meat and no distinction need be made between the yields of cows and bulls.

3.2 Introduction

As human population projections continue to increase, factors such as climate change, political and financial instability, etc. threaten to destabilize the agricultural sectors of developing countries which could be detrimental to future food security (Ericksen et al., 2009; Otieno & Muchapondwa, 2016). Dealing with the uncertainties around food production is naturally easier for established, financially secure institutions and producers, but for the small scale farmer adapting to an ever changing environment and market is easier said than done. If it is not possible for a farmer to afford or update redundant technologies and systems, expand grazing or acquire what is needed to manage a farm, they will not be able to compete or even exist alongside commercial producers. Consequently, if small scale farmers and producers are unable to compete with the economies of scale, they will be forced to consider alternative options to traditional farming where production is maintained while input costs are lowered, while adapting to the challenges specific to each farm.

The need for alternative agricultural enterprises can potentially be met by means of incorporating game farming into traditional farming systems. Game species offer region specific adaptation to climate, diseases and vegetation and have an advantage over domestic meats because of its lean, “organic” nature (Hoffman & Wiklund, 2006). The main benefit of farming with game species above domestic species is the fact that they are better adapted to South Africa’s circumstances resulting in less input costs for the farmer (Skinner, 1967b). However due to irregular and uncontrolled supply, the market for game meat is not nearly as established locally as it potentially could be. This leaves potential for up and coming farmers to fill the gap with little competition from the rest of the industry as the main focus is not yet on meat production, but rather hunting and eco-tourism. Together with this, exports can potentially increase as the benefits and availability of game meat become more apparent.

In order for game farming to be a viable alternative to farming with domestic species, game species have to be able to compete not only in terms of meat quality and characteristics, but also in terms of carcass composition and production traits. Although it is common knowledge that eland are the largest of the African antelope species, there is limited scientific research describing the carcass composition and muscle weights of both sexes. The purpose of this study is to provide basic information on the weights of the organs, intestines and carcass yields during slaughter of eland bulls and cows. This will help to better understand the carcass composition of eland and determine if it is necessary to distinguish between male and female animals.

3.3 Materials and methods

3.3.1 Harvest and slaughter

Twelve (six male, six female) eland were harvested on the Prinskraal farm near Bredasdorp in the Western Cape Province of South Africa (34°37'45.1"S 20°06'44.9"E, 15.4 m above sea level). The six bulls were all young bulls (younger than 2 years of age) as only a few selected older bulls are maintained on the farm for breeding purposes; cows were randomly harvested without taking age into account. Harvesting took place in the late afternoon and early morning and was done in accordance with the standard operating procedure (ethical clearance number: 10NP_HOF02). Animals were harvested on two separate occasions within the period of one month between the months of June and July 2016. Animals were either shot in the upper neck area or in the lower chest behind the shoulder. Animals that were killed by more than one shot or that possibly suffered from ante-mortem stress were documented. Immediately after the kill shot, the animals were exsanguinated by cutting the jugular vein and carotid arteries. Shortly after each animal was bled in the field, they were transported to the slaughtering facilities (about five minutes' drive). Here the carcasses were skinned and the head and trotters were removed before evisceration. Thereafter the warm carcass, organs and offal weights were recorded. After the carcasses were dressed they were divided into quarters (split along the midline and quartered between the 3rd and 2nd last rib) so that they could be suspended in the cold truck (0-5°C) for transportation back to the meat processing lab at the Department of Animal Sciences at the University of Stellenbosch.

3.3.2 Processing and sampling

Carcass quarters were transferred to a refrigerator (1-5 °C) upon arrival at the department and were processed the following day (day 2 post-mortem). Around 36 hours post-mortem the cold weight of each carcass was calculated by summation of the weights of the individual quarters. Thereafter seven muscles were removed from the quarters and their pH measurements and weights were recorded. The muscles that were removed included the *M. infraspinatus* (IS)*, M. supraspinatus* (SS)*, M. longissimus thoracis et lumborum* (LTL)*, M. psoas major* (PM)*, M. biceps femoris* (BF)*, M. semimembranosus* (SM)*, M. semitendinosus* (ST). After weighing the muscles they were assigned to the different trials and processed accordingly (Chapters 4-6).

3.3.3 Statistical analysis

The main factor in the experimental design was sex, with animal as random repetition. Analysis of variance (ANOVA) was conducted on all variables assessed using the GLM procedure of SAS software (Version 9.4, SAS Institute Inc., Cary, NC, USA). A Shapiro-Wilk test was done to test data for deviation from normality (Shapiro and Wilk, 1965). One animal was identified as an outlier but still included in the analysis. The particular male was significantly lighter than the rest of the animals and decreased most of the mean weights of the measurements taken from males. Furthermore three of the six cows were pregnant, which would lower the dressing percentage of the females. None the less, due to limited sample numbers, all animals were used in the statistical analyses.

Least squares means (LSMeans) were computed and compared using pairwise p-values. A probability level of 5% was considered significant for all significance test.

3.4 Results

3.4.1 Measurements at slaughter

The weight measurements recorded for both genders during slaughter are represented in Table 3.1, together with their *P*-values. The dressing percentage was calculated by dividing the dressed weight with the warm carcass weight and was calculated at 48.6 ± 1.18 % for cows and 50.8 ± 1.46 % for bulls. Although the bulls had heavier head weights, this did not differ (P = 0.262) from that of the cows, thus the mean head weight for all 12 animals was 14.3 ± 2.09 kg. Trotters also did not differ (P = 0.836) between sexes. Cows had heavier skins than bulls, although the difference was not significant (P = 0.068). The pluck was heavier for females, again linked to their live weight but did not differ significantly from that of the males. The average testicle weight for the six males was 250.5 ± 3.46 g and the three females that were pregnant had an average udder weight of 1.9 ± 0.33 kg. Furthermore their unborn calves and placenta had an average weight of 25.8 ± 4.47 kg which is roughly seven percent of their live weights.

3.4.2 Cold carcass and muscle weights

The recorded measurements for both sexes after the end of *rigor mortis* are represented in Table 3.2 and split between cold carcass weights and muscle weights. The difference between warm and cold carcass weights were 3.8 and 3.1 kg for cows and bulls, respectively. The differences between the weights of the hind quarters and fore quarters were 7.5 kg for females and 5.1 kgs for males. This is again indicative of the young age of the males since their fore quarters would have been heavier than the hindquarters if they were fully developed in the neck, chest and shoulder areas. None of the muscles weights differed significantly between sexes. The LTL (3.99-4.21 kg), BF (3.27-4.04 kg) and SM (3.39-3.75 kg) were the heaviest of the seven muscles removed from the carcass and was on average three to four times the weight of the IS (1.15-1.32 kg), SS (0.86-1.15 kg), PS (0.99-1.22 kg) and ST (1.33-1.60 kg).

Table 3.1 Effect of sex on eland warm carcass weight measurements (LSMean ± SEM).

	Cows (n=6)	**Bulls** (n=6)	***P*-value**
Carcass (kg)	357.2 ± 14.6	305.4 ± 23.34	0.090
Dressed carcass (head off) (kg)	173.6 ± 8.87	156.9 ± 15.08	0.361
Dressing %	48.6 ± 1.18	50.8 ± 1.46	0.251
Head (kg)	13.6 ± 0.65	15.0 ± 1.01	0.262
Trotters (kg)	7.2 ± 0.34	7.0 ± 0.38	0.836
Skin (kg)	24.9 ± 0.85	20.3 ± 2.08	0.068
GIT (with contents) (kg)	88.5 ± 7.42	83.2 ± 4.13	0.591
Liver (kg)	5.2 ± 0.33	4.4 ± 0.31	0.099
Heart (kg)	2.1 ± 0.21	1.7 ± 0.12	0.087
Trachea + Lungs (kg)	5.4 ± 0.43	4.7 ± 0.52	0.368
Kidneys (kg)	1.1 ± 0.25	0.8 ± 0.05	0.264
Spleen (kg)	0.5 ± 0.02	0.5 ± 0.04	0.744
Testicles (g)		250.5 ± 3.46	
Udder (kg)	1.9 ± 0.33		
Calf + Placenta (n=3) (kg)	25.8 ± 4.47		

LSMean: least squares mean; SEM: standard error of the mean; GIT: gastro intestinal tract.

Table 3.2 Effect of sex on the eland cold carcass and muscle weight measurements (LSMean ± SEM).

	Cows	**Bulls**	***P*-value**
Cold carcass weights			
Whole carcass (kg)	169.8 ± 8.79	153.8 ± 15.20	0.384
Forequarters mean (kg)	38.7 ± 2.64	35.9 ± 3.71	0.557
Hindquarters mean (kg)	46.2 ± 1.82	41.0 ± 3.92	0.255
Muscle weights (kg)			
IS	1.32 ± 0.11	1.15 ± 0.17	0.428
SS	1.15 ± 0.11	0.86 ± 0.10	0.073
LTL	4.21 ± 0.21	3.99 ± 0.44	0.663
PM	1.22 ± 0.05	0.99 ± 0.13	0.126
BF	4.04 ± 0.24	3.27 ± 0.33	0.090
SM	3.75 ± 0.13	3.39 ± 0.31	0.318
ST	1.60 ± 0.05	1.33 ± 0.15	0.115

LSMean: least squares mean; SEM: standard error of the mean.

3.5 Discussion

3.5.1 Measurements at slaughter

Carcass yield information for eland, as with other game species, is relatively limited since they are mostly hunted and not yet farmed on a commercial scale as with domesticated livestock. Hoffman and colleagues (2015) reported cold carcass weights of 178.2 ± 14.58 kg for eland bulls and 206.7 ± 14.62 kg for cows harvested in Namibia. These eland were between the ages of two and six years, with two of the females being about ten years old, possibly explaining why the females had a higher mean carcass weight. Also, both in Namibia and in the present study, large mature bulls are normally kept for trophy hunting and thus younger animals were selected for these experiments as the value of a trophy bull is much higher than that of a young cull bull or cows. At the Czech University of Life Sciences' farm (Lány), the average weight at slaughter for male eland (*T. o. pattersonianus*) around the age of three years was approximately 410 kg (Bartoň et al., 2014). It should be noted that the breeding herd established in 2006 at Lány, currently consisting of animals of the sixth and seventh generations born in captivity, are from the Patterson's sub-species. Their heavier weight could therefore be an indication of potential size differences between sub-species of common eland, but is most likely due to the fact that these Livingstone's are fed a grain based diet with limited daily activity and were also older. Posselt (1963) reported that the eland raised at Lupani in Zimbabwe achieved slaughter weights of around 410 kg for females and 515 kg for males after 4 years. The eland at Lupani reached the same weight as the eland in this trial after 2 – 2.5 years, which could potentially aid in determining the age of the eland harvested at Prinskraal. Furthermore Posselt calculated dressing percentages of between 58 and 60% which is considerably higher than the current study, however the three pregnant cows and young/small bull that was included in the present analysis is most likely responsible for lowering the dressing percentage. Another explanation for these low dressing percentages could be due to the seasonal influence on the body condition of the eland. Since the eland were harvested during the cold, wet winter months of June and July it is to be expected that the environmental stress would have an impact on the carcass composition of the animals, resulting in a lower meat to bone ratio (Neethling & Hoffman, 2014). Von La Chevallerie and colleagues (1971) found a similar dressing percentage of 51.3% for the six bulls in their trail, but the eland castrates to which they were compared had a mean dressing percentage of 63.2%. Dressing percentage as well as fat content has previously been improved by castrating animals at around four months (Skinner, 1967b).

Compared to other game species that have dressing percentages normally exceeding 50 %, the eland that were harvested for this study had lower dressing p2015ercentages (Fitzhenry et al., 2016; Hoffman et al., 2009; Neethling & Hoffman, 2014; Smit, 2004), however the results are in line with what is known for domestic species such as cattle and sheep (Cloete et al., 2000; Onyango et al., 1998). Pollock & Litt (1969) who investigated game ranching in Rhodesia (currently Zimbabwe), found that the average dressed weight for eland was around 270 kg, which is higher than the current study indicating an older average age for those animals. Lindsey (2011) reported that farmers in Namibia received the highest price per kilogram for eland, 14 rand per kilogram higher than the average price for game meat. This together with the size of eland muscles and retail cuts compared to other game will result in a higher turnover per animal, matched with equal meat quality characteristics.

In developing countries, especially in Africa and Asia, organs and edible offal form an important part of the human diet (Fatma & Mahdey, 2010). Offal can be divided into white offal (brains, teats, marrow, testicles, feet, head, tripe, caul and sweetbreads) and red offal (heart, tongue, lungs, spleen and kidneys). Offal is rich in nutrients and the kidneys and liver are particularly rich in iron. The GIT (gastro-intestinal tract) is normally removed first after which it is thoroughly cleaned of any contents and used as tripe. Van Zyl (1962) reported on the carcass weights of an eight and a half year old bull that was slaughtered in 1952 at the S.A. Lombard nature reserve. The GIT weighed 69.3 kg which is significantly lighter compared to the GIT's of the bulls in this study, considering that their average live weight is around a 140 kg less than that of the bull. However the fact that the eland bull had no access to feed for 12 hours before slaughter is most likely the cause of this lower weight. Van Zyl further recorded the empty GIT weight as 24.83 kg and calculated that it was around 35.8 % of the full stomach and intestinal weight. If this same percentage is applied to the current study, the empty GIT weight would be roughly 31.7 kg and 29.8 kg for cows and bulls, respectively. Tripe is popular among all cultures in South Africa and is normally cut up into small pieces and stewed in a curry sauce with baby potatoes and served over rice (Erasmus & Hoffman, 2017).

The head of an animal also offers substantial meat in the form of the brain, tongue and cheeks and these are even regarded as delicacies by some cultures. The head of the above mentioned bull (Van Zyl, 1962) was around 20.0 kg which is much heavier than that measured for the six males (15.0 kg). Besides a larger skull the difference in head weight can most likely be ascribed to larger horns on the bull, since the six males that were harvested at Prinskraal were still young with undeveloped horns. Mature eland bulls are trademarked by their thick horns (especially around the base) and dark tuft of hair on the forehead, but these features only develop after the age of six years. The farmer at Prinskraal manages the herd so that there are only two dominant bulls at any one time to avoid fighting and injuries, the six bulls that were harvested can therefore be classified as sub-adult since they did not challenge the mature bulls yet. Further support for their young age can be gathered from the early work of Posselt (1963) who recorded the weights of nine males throughout different life stages. If the live weights of the six eland are compared with those of Posselt, their age can be estimated at around one and a half to two years; ages that correspond to the information supplied by the farmer. Also, the trotters did not differ in weight between sexes which was expected since the young males only develop larger front hooves as their neck and chest gains size with maturity (Flack, 2013).

The testicles, udder and teats are usually removed as the animals are skinned. These parts can also be consumed, however it is usually passed on to more adventurous eaters. Eland skins were valued during the days of the early settlers as they were used to fix ox wagons and for other leather products (Mossman & Mossman, 1976). In later years, eland skins were processed and tanned for the export market together with zebra, lion and other big game skins. These days the game tanning industry focuses primarily on animal skins used in fashion or furniture such as that of ostrich, crocodile and zebra. Von La Chevallerie et al. (1971) reported that the average skin weight of six eland bulls varying in age was 6.6 % of the average live weight, translating to around 27 kg wet weight which is in line with the current findings (6.9 and 6.6 % of live weight for cows and buls, respectively). The organs located in the thoracic cavity can easily be accessed after the GIT has been removed. The pluck (heart, liver, lungs and trachea) made up 3.5-3.6 % of the eland's live weight which is slightly more than that of Van Zyl's eland bull (2.9 %). These organs do not require as much cleaning and rinsing as the tripe and in the field are often cooked immediately (usually kidneys) after slaughter and enjoyed amongst hunters.

Offal contributes around 33 % of the edible portion of the carcass. Offal not destined for human consumption can also be utilized in the pet food industry or processed into feed for certain aquatic species such as catfish (Murray et al., 1997). Furthermore it can be processed in a rendering plant, producing material that is used for fertilizer or fuel.

3.5.2 Cold carcass and muscle weights

As expected the cold carcass weight was less than the warm carcass weight due to moisture loss in the form of blood, water and mucus over the period of *rigor mortis* development and chilling. The difference between warm and cold carcass weight was more apparent for cows than bulls (3.8 and 3.1 kg difference, respectively). In general, female animals will mature earlier and both immature and mature female game animals usually have higher hindquarter percentages (in relation to whole carcass weight) in comparison with mature male animals (Ledger, 1963).

Of the seven muscles removed, the LTL was the heaviest for both sexes which is promising since this muscle is regarded as more valuable in beef due to its superior tenderness and lean nature. Furthermore it is a popular muscle to use for biltong production, since its elongated shape allows for longer biltong cuts along the muscle grain (Jones et al., 2017). Some of the finest muscle cuts are usually found in the hindquarters and these include the BF and SM which contribute around 15-20 % of the total hind quarter weight. They had similar weights between sexes, except for the BF which was heavier than the SM in the cows, but the opposite was found for the bulls. These two muscles have developed over time to perform the primary functions of locomotion and jumping and with that their size increased in relation to other less important muscles (Frandson et al., 2009). Corresponding to their size, the BF and SM (and sometimes the LTL) muscles have been reported to have thicker muscle fibres i.e. a more coarse grain (Herring et al., 1965; Klont et al., 1998). For both sexes, the ST was fourth heaviest, which is also a muscle located in the hind quarters, further increasing the meat to bone ratio of the hind quarters. The PM is one of the most tender muscles found on a carcass due to its small size and muscle fibre diameter as well as lack of activity and therefore less connective tissue (Herring et al., 1965). The two muscles found on the fore quarters had the lightest weights and were around three to four times lighter than the BF and SM. These muscles are smaller because they serve a different purpose to the muscles that aid in propulsion; the IS muscle primarily acts as a very strong shoulder joint ligament and furthermore serves to flex, move and stabilise the shoulder (Frandson et al., 2009; Totland & Harald, 1991). The SS muscle primarily performs as a ligament of the shoulder joint, although it may assist with the extension of the shoulder (Frandson et al., 2009).

3.6 Conclusion

Carcass dressing percentages were not as high as for other game species, which could be due to the seasonal influence on body composition. The yields did however compare favourably with that of domestic species, which could potentially be highlighted when the two species are compared in a challenging environment. Furthermore eland offer a large portion of edible offal that is utilized in Africa by lower income households. The large muscle cuts allow for better processing into value added products such as aged steaks or biltong, potentially improving the profit margin. It has also been established that there is no need for distinction between sexes since none of the variables that were recorded differed significantly between cows and these young bulls. The carcass yield differences between sub-species could be an interesting topic for future research since they have only been separated based on their coat colour variations. Similarly it would be interesting to compare the carcass yields of eland with *Bos taurus* and *Bos indicus* cattle breeds in a feedlot system as well as in a challenging, unproductive environment. Some work has been done on the production of castrated eland, however these studies are limited and dated and further research could therefore aid in uncovering the advantages and disadvantages of using castration on eland as well as other game species, although it should be noted that castration (although practised in South Africa) is against the Norms and Standards of the Wildlife ranching South Africa (WRSA).

3.7 References

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. Meat Science, 96, 346–352.

Cloete, S. W. P., Snyman, M. A., & Herselman, M. J. (2000). Productive performance of Dorper sheep. *Small Ruminant Research*, 36, 119–135.

Erasmus, S. W., & Hoffman, L. C. (2017). What is meat in South Africa? *Animal Frontiers*, 7, 71-75.

Ericksen, P. J., Ingram, J. S., & Liverman, D. M. (2009). Food security and global environmental change: emerging challenges. *Environmental Science & Policy*, 12, 373–377.

Fatma, H. M. A., & Mahdey, E. A. (2010). Incidence of *brucella* species in slaughtered food animals and its edible offal at Beni-suef, Egypt. *Global Veterinaria*, 5, 248–254.

Fitzhenry, L. (2016). Yields and Meat-Quality attributes of wild Fallo deer (*Dama dama*) in South Africa. Master's Thesis, Stellenbosch University.

Frandson, R. D., Wilke, W. L., & Fails, A. D. (2009). *Anatomy and physiology of farm animals*. New Jersey: John Wiley & Sons.

Herring, H. K., Cassens, R. G., & Briskey, E. J. (1965). Further studies on bovine muscle tenderness as influenced by carcass position, sarcomere length, and fiber diameter. *Journal of Food Science*, 30, 1049–1054.

Hoffman, L. C., Mostert, A. C., Kidd, M., & Laubscher, L. L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science*, 83, 788–795.

Hoffman, L. C., Van Schalkwyk, D., McMillin, K. W., & Kotrba, R. (2015). Intramuscular fat characteristics of Namibian common eland (*Tragelaphus oryx*). African Journal of Wildlife Research, 45, 312–320.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison - meat for the modern consumer. *Meat Science*, 74, 197–208.

Jones, M., Arnaud, E., Gouws, P., & Hoffman, L. C. (2017). Processing of South African biltong – A review. *South African Journal of Animal Sciences*, 47, 743–757.

Klont, R. E., Brocks, L., & Eikelenboom, G. (1998). Muscle Fibre Type and Meat Quality. *Meat Science*, 49, 219–229.

Ledger, H. P. (1963). Animal husbandry research and wildlife in East Africa. *African Journal of Ecology*, 1, 18–28.

Lindsey, P. (2011). An analysis of game meat production and wildlife-based land uses on freehold land in Namibia: Links with food security. TRAFFIC, East/Southern Africa.

Mossman, S. L., & Mossman, A. S. (1976). Wildlife utilization and game ranching: Report on a study of recent progress in this field in Southern Africa. International Union for Conservation of Nature and Natural Resources occasional paper no. 17. Morges, Switzerland.

Murray, S. M., Patil, A. R., Fahey, G. C., Merchen, N. R., & Hughes, D. M. (1997). Raw and rendered animal by-products as ingredients in dog diets. *Journal of Animal Science*, 75, 2497–2505.

Neethling, J., & Hoffman, L. C., Britz, T. J. (2014). Impact of season on the chemical composition of male and female blesbok (*Damaliscus pygargus phillipsi*) muscles. *Journal of the Science of Food and Agriculture, 94, 424-431.*

Onyango, C. A., Izumimoto, M., & Kutimaa, P. M. (1998). Comparison of some physical and chemical selected game meats. Meat Science, 49, 117–125.

Otieno, J., & Muchapondwa, E. (2016). Agriculture and adaptation to climate change : The Role of wildlife ranching in South Africa Agriculture and adaptation to climate change. Economic Research Southern Africa, working paper no. 579.

Pollock, N. C., & Litt, M. A. B. (1969). Some observations on game ranching in Southern Africa. *Biological Conservation*, 2, 18–24.

Posselt, J. (1963). The domestication of the eland. *Rhodesian Journal of Agricultural Research*, 1, 81-87.

Skinner, J. D. (1967). Eland vs. Beef: Eland cannot compete, except in hot semi-arid regions. *African Wild Life*, 26, 4–9.

Smit, K. (2004). Meat quality characteristics of blesbok (*Damaliscus dorcas phillipsi*) and red hartebeest (*Alcelaphus buselaphus caama*) meat. Doctoral dissertation, Stellenbosch University.

Totland, G. K., & Kryvi, H. (1991). Distribution patterns of muscle fibre types in major muscles of the bull (*Bos taurus*). *Anatomy and Embryology*, 184, 441–450.

Van Zyl, J. H. M. (1962). The meat production of South African game animals. 1: The Eland. *Fauna and Flora*, 13, 35-40.

Von La Chevallerie, M., Erasmus, J. M., Skinner, J. D., & Van Zyl, J. H. M. (1971). A note on the carcass composition of the common eland (*Taurotragus oryx*). *South African Journal of Animal Sciences*, 1, 129–131.

Chapter 4: Influence of sex on the physical qualities and proximate composition of six muscles from common eland (*Tragelaphus oryx*)

4.1 Abstract

This study aimed to determine and compare the physical quality and proximate composition of six eland muscles from both males and females. The pH of all the muscles fell within the normal range (5.5-5.9), although the IS (which had the highest pH) displayed signs of DFD compared to the other muscles. These included the lowest CIE lightness value (L* = 32.3), lowest drip and cooking losses (0.5 and 27.2 %, respectively) and a low shear force (65.5 N). Most of the physical measurements were normal for red meat, except for the shear force being higher than for other game species with the *Longissimus thoracis et lumborum* (LTL) having the highest shear force (97.6 N). The CIE colour measurements were in line with what is expected from game meat (L* = 32.3-37.5, a* = 12-15.5 and b* = 10.6-12.9). The proximate composition of the muscles did not vary and was in line with the composition of other game species except for having slightly higher moisture contents (75.6-77.8 %) and proportionally lower protein contents (20.3-23.0 %). However the lean to fat ratio of eland meat is still more favourable than that of domestic species. This study has shed new light on the nutritional value of eland meat, which will be important for product labelling and incorporation into food composition databases, but is also useful for nutritional education, marketing and export purposes.

4.2 Introduction

South African game ranch owners and hunters are fortunate to have access to a large bounty of species to farm with and hunt. South Africa is also an established exporter of game meat and a popular destination for hunters and eco-tourists alike (Hoffman & Wiklund, 2006). Unfortunately, consumers are generally uninformed about the benefits of game meat consumption since there has been limited research published with regards to individual species' meat qualities and composition. These meat attributes need to be investigated thoroughly for each species as factors such as size, diet and habitat all influence the meat composition. This information is needed to inform consumers of the benefits of game meat consumption by means of strategic marketing plans. The fact that game meat can be marketed as "free range" and "organic" (Hoffman & Wiklund, 2006) adds potential value because it is viewed as healthier and more acceptable by the general public compared to the intensively farmed counterparts. This is of interest since there has been a shift amongst most consumers towards healthier, safer products, especially with fresh meat (Hoffman & Wiklund, 2006). Consumers do not only expect nutritional requirements to be met, but factors such as freshness, lean to fat ratio, flavour and tenderness are of equal importance (Dransfield, 2001, 2003; Ngapo & Dransfield, 2005).

Compared to other game species, there has been limited published research on eland meat even though this species has been identified for possible domestication and intensive production (Charles et al., 1981). The only previous study that reported on the proximate composition of both male and female eland was conducted by Hoffman and colleagues (2015) on common eland from Namibia. Significant differences were found in the fat content between male and females (1.2 % and 2.1 %, respectively), whereas the moisture, ash and protein contents were the same in both sexes.

Von La Chevallerie (1972) compared the meat composition of the LTL muscle from male eland and six other game species with each other and found that the eland had the highest fat content (2.4 %) of all the species and a slightly higher moisture content (75.8 %). Bartoň and colleagues (2014) compared six male eland with cattle raised under similar circumstances and found that eland had a slightly higher protein content (21.85 %) and seven times less fat (2.00 %) than beef (14.10 %). The eland LTL's that were used in the above mentioned study had particular low fat content's compared to other studies (Hoffman et al., 2015; Von La Chevallerie (1972).

Eland meat has not been thoroughly studied in terms of proximate composition and physical characteristics, especially with regards to female animals that have been excluded in most of the previous studies. Another limitation is that the few studies referenced were limited to only testing the LTL muscle. The purpose of this study was therefore to gather data on the proximate and physical composition of six major muscles from male and female eland to investigate differences between sexes and muscle types.

4.3 Materials and methods

4.3.1 Harvest and slaughter

Twelve (six bulls, six cows) eland were harvested on the Prinskraal farm near Bredasdorp in the Western Cape Province of South Africa. Harvesting took place in accordance with the standard operating procedure (ethical clearance number: 10NP_HOF02). Animals were harvested on two separate occasions within the period of one month between the months of June and July 2016. After a kill shot to the head or chest, the animals were exsanguinated and transported to the slaughtering facilities to be skinned and eviscerated. Carcasses were then suspended in the cold truck (0-5 °C) for transportation back to the meat processing lab at the Department of Animal Sciences at the University of Stellenbosch. See Chapter 3 for more detail.

4.3.2 Sampling

Carcasses were transported in a refrigerated trailer (<4 °C) and transferred to a refrigerator (2-4 °C) upon arrival at the Meat Laboratory in the Department of Animal Sciences, Stellenbosch University and were processed the following day (day two post-mortem). Six muscles were removed from the right side of each carcass, three from the hind quarters, two from the front quarters and one from the back. Two small portions were removed from the *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles for physical and chemical analysis and the remaining portions were further divided to determine the effect of refrigeration ageing on the meat quality attributes (Chapter 6). The other muscles that were analysed include the *Semimembranosus* (SM), *Semitendinosus* (ST), *Infraspinatus* (IS) and *Supraspinatus* (SS) muscles.

4.3.3 Physical analysis

4.3.3.1 pH

The ultimate pH (pH_u) was measured for all muscles ~36 hours post-mortem after the muscles were removed from the carcass. This would allow sufficient time for the full resolution of rigor prior to measurement. The pH was measured as close to the centre of each muscle using a calibrated (pH standard buffers at pH 4.0 and pH 7.0) Crison ICRI2502 portable pH meter.

4.3.3.2 Surface colour

Six colour measurements per sample were taken at random locations after drip and cooking loss steaks (each ~2.0 cm thick) were cut and left to bloom for 30 minutes. The measurements were in accordance to the CIE L*a*b* colour system (Honikel, 1998). The CIE L* (lightness), a* (green-red value) and b* (blue-yellow value) values were measured using a Color-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany). Thereafter the CIE a* and b* values were used to calculate the chroma value (saturation/colour intensity) and hue-angle (colour definition) by means of the following equations:

Hue-angle (°) = $\tan^{-1}(b^*/a^*)$

Chroma (C*) = $(a^{*2} + b^{*2})^{0.5}$

4.3.3.3 Drip loss

One ~2.0 cm thick steak from each muscle was used for a drip loss test to determine the water holding capacity of the meat. Steaks were first weighed to determine the initial weight and then suspended with a wire in an inflated polyethylene bag so as to catch any moisture extruded from the sample during this period. Samples were placed in the bags in such a way that it did not touch the sides, top or bottom of the bag. The samples were hang in a refrigerator (2-4 °C) for 24 hours after which they were removed from the plastic bags, blotted dry and weighed to determine the final weight. The moisture lost during the suspension period was then used to calculate the drip loss as a percentage of the initial weight of the sample.

4.3.3.4 Cooking loss

One ~2.0 cm thick steak was selected from each muscle and weighed before it was suspended in a water-bath (model 102 digital electrical bridge thermostat; model 132A 40 l water-bath; Scientific, Roodepoort, South Africa) set to 80 °C to cook. To allow for complete cooking the samples were left in the water-bath for 50 minutes before they were removed and placed in a refrigerator (2-4 °C) to cool down overnight. The following day they were removed from the refrigerator, blotted dry and weighed to determine the final cooked weight. This weight could then be compared to the initial weight of the raw sample so that the moisture lost during cooking could be determined. The cooking loss was expressed as a percentage of the initial raw weight of the samples (Honikel, 1998).

4.3.3.5 Warner-Bratzler shear force

The tenderness of the muscles was determined by using a model 3345 Instron Universal Testing Machine (Apollo Scientific cc, Alberta, Canada) fitted with a Warner-Bratzler blade. The Instron had a load cell of 5 kN and the blade sheared at a crosshead speed of 200 mm/min. The Warner-Bratzler fitting was 1.2 mm thick and had a triangular opening with a base length of 13 mm and a perpendicular height of 15 mm.

Six samples were taken from each cooking loss steak to be used for the Warner-Bratzler shear force test. Two scalpels fixed at a distance of 1 cm from each other were used to cut through the 2 cm thick steaks so as to produce a rectangular prism of 1 cm x 1 cm x 2 cm that ran parallel with the muscle fibres. Each sample was then individually cut by the blade perpendicular to the longitudinal axis of the sample/fibres. The force in Newton required to shear through the muscle fibres was measured and the average of the six measurements was then used to determine the Warner-Bratzler shear force of each muscle (Honikel, 1998).

4.3.4 Proximate analysis

The portions from all of the muscles were divided according to the amounts needed for the different analyses, homogenised and placed in a – 80 °C freezer until analysed.

A 2.5 g portion of each muscle was used to determine the moisture content (g/100 g) at 100 °C (24h) according to the AOAC official method 934.01 (AOAC, 2002a).

A rapid solvent extraction method as described by Lee et al. (1996) using chloroform/ methanol (1:2 v/v) was used to determine the Intramuscular fat content (IMF) content of a 5 g meat sample from each muscle.

The filtrate from the fat extraction was consequently dried and analysed in a Leco Nitrogen/Protein Analyser (Leco Fp-528, Leco Corporation). The crude protein content (g/100 g) was determined according to the Dumas combustion method 992.15 (AOAC, 2002c) from a dry, de-fatted, finely ground sample, encapsulated in a LecoTM foil sheet. The results from this method are given as the nitrogen content (% nitrogen), which was then further multiplied by a conversion factor of 6.25 (as meat protein is assumed to contain 16 % nitrogen and therefore 100/16) to determine the total crude protein (g/100 g) within each sample (McDonald *et al*., 2002). Preceding each batch of muscle samples the Leco Nitrogen/Protein Analyser was calibrated with an EDTA calibration sample (Leco Corporation, 3000 Lake View Avenue, St. Joseph, HI 49085-2396, USA, Part number 502-092, lot number 1038) to ensure accuracy throughout the testing.

After the moisture was extracted from the samples the ash content (g/100 g) was determined at 500°C (6h) according to the AOAC official method 942.05 (AOAC, 2002b).

4.3.5 Statistical analysis

The experimental design was a completely random split plot with sex as main plot factor and muscle as subplot factor. Six each of male and female eland were selected at random, resulting in 12 eland carcasses (n = 12) in total. Six muscles (BF, IS, LTL, SM, SS and ST) from each carcass were analysed, giving a total of 72 samples.

Analysis of variance (ANOVA) was conducted on all variables assessed using the GLM procedure of SAS software (Version 9.4, SAS Institute Inc., Cary, NC, USA), according to the model for the experimental design indicated by:

$Y_{ijk} = \mu + G_j + G(R)_{ij} + M_k + GM_j + \varepsilon_{ij}$

Where:

y_{ijk} is the response obtained for the i^{th} session for the j^{th} sample μ is the overall mean,

G_j is the sex (gender) main plot effect,

$G(R)_{ij}$ is the correct error term for testing the sex main plot effect,

M_k is the muscle subplot effect

GM_{jk} is the sex by muscle interaction effect and

ε_{ijk} is correct error term for testing the muscle subplot effect and interaction.

A Shapiro-Wilk test was done to test data for deviation from normality (Shapiro & Wilk, 1965). Least squares means (LSMeans) were computed and compared using pairwise p-values. A probability level of 5 % was considered significant for all significance test.

4.4 Results

4.4.1 Physical analysis

None of the physical measurements were affected by sex, however interactions existed between muscle and sex for the drip loss percentage, the CIE L* and b* values (Fig. 4.1). The drip loss percentage was higher ($P \leq 0.05$) for female BF, LTL and SM muscles whilst males had higher ($P \leq 0.05$) drip loss for the IS, SS and ST muscles (Fig. 4.1 (a)). Males had higher ($P \leq 0.001$) CIE L* values for all the muscles except the BF and SM (Fig. 4.1 (b)). Females had higher ($P \leq 0.05$) CIE b* values for the BF, LTL and SM, while males had higher values for the SS and ST (Fig. 4.1 (c)).

Despite the interactions, the main effects of muscle type were still interpreted for a better understanding of the data ignoring sex as main effect and only focusing on muscle type as main effect (Table 4.2). Muscle type influenced ($P \leq 0.001$) all of the measurements. The SM had the lowest pH_u and the IS had the highest pH_u (>5.8). Drip loss percentage was highest in the SM, LTL and SS muscles and equal but less for the other muscles. Cooking loss percentage was highest in the SM, SS and ST and lowest in the IS. Warner-Bratzler shear force was also the lowest for the IS and the highest for the LTL. The ST had the highest CIE L* value, the SS the highest a* value and both the SM and ST the highest b* value. Chroma was the highest in the SM and lowest in the LTL. The ST had the highest hue-angle value while the two front quarter muscles had the smallest hue-angle.

4.4.2 Proximate analysis

There was no interaction of muscle and sex for any of the measurements, therefore the main effects of muscle type and sex were interpreted further (Table 4.2). Sex had no influence on any of the measurements, however muscle type influenced all of the measurements ($P \leq 0.0001$). The moisture content was the highest in the BF, SS, IS and ST. Protein was highest in the SM and LTL and lowest in the BF. Intramuscular fat content was the highest in the BF and the lowest in the LTL. The BF, SM, LTL and ST had the highest ash content.

Table 4.1 Level of statistical significance (P - values) for the main effects of sex and muscle and their interaction of the physical measurements of eland meat.

	Gender	Muscle	Gender x Muscle
Physical analysis			
pH	0.4544	≤0.0001	0.07
Drip loss	0.4064	0.0006	0.0012
Cooking loss	0.8049	≤0.0001	0.5598
WBSF	0.8238	0.0006	0.2941
L*	0.3871	≤0.0001	0.0007
a*	0.4114	≤0.0001	0.3246
b*	0.5423	≤0.0001	0.0236
Chroma	0.4389	≤0.0001	0.0896
Hue-angle	0.4166	≤0.0001	0.5735
Proximate analysis			
Moisture	0.1593	≤0.0001	0.3334
Ash	0.3719	≤0.0001	0.2361
DM	0.1593	≤0.0001	0.3334
Fat	0.828	≤0.0001	0.1274
Protein	0.181	≤0.0001	0.3407

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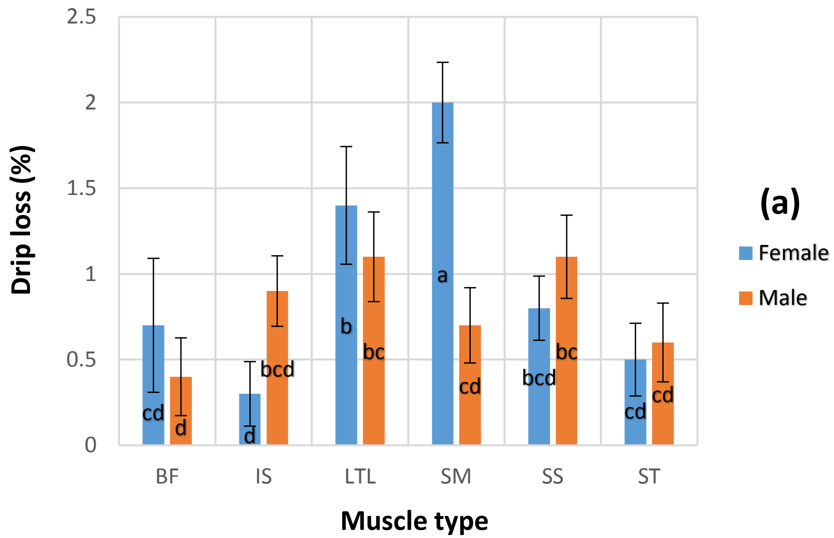
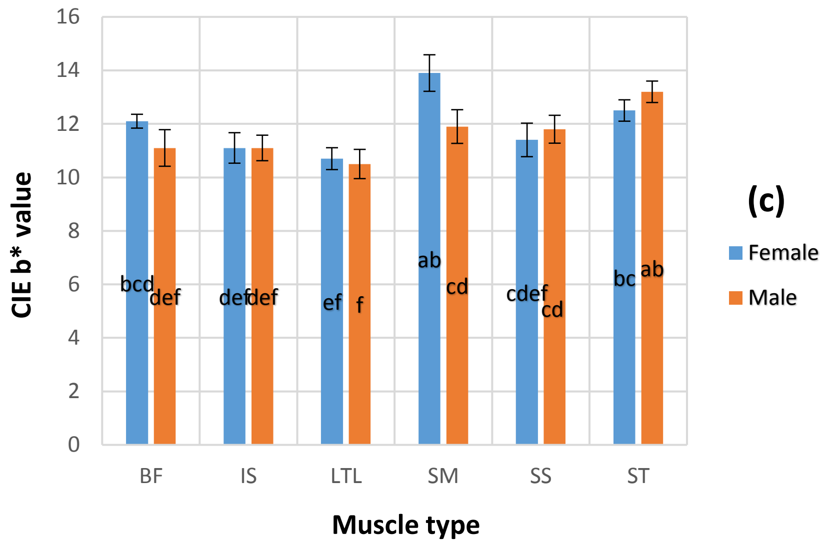
Table 4.2 The muscle differences in the physical qualities and chemical composition of the six eland muscles (LSMeans ± SEM)

	Hind quarter			Back	Fore quarter	
	BF	**SM**	**ST**	**LTL**	**IS**	**SS**
Physical analysis						
pH$_u$	5.6^{bc} ± 0.09	5.5^{c} ± 0.08	5.6^{bc} ± 0.05	5.5^{bc} ± 0.04	5.9^{a} ± 0.09	5.7^{b} ± 0.08
Drip loss (%)	0.5^{b} ± 0.22	1.4^{a} ± 0.26	0.5^{b} ± 0.15	1.2^{a} ± 0.21	0.5^{b} ± 0.16	1.0^{ab} ± 0.15
Cooking loss (%)	31.3^{b} ± 1.68	37.3^{a} ± 0.71	35.2^{a} ± 0.95	30.5^{b} ± 0.73	27.2^{c} ± 0.82	35.3^{a} ± 1.14
WBSF (N)	91.5^{ab} ± 6.44	78.7^{bc} ± 6.15	77.5^{bc} ± 3.59	97.6^{a} ± 5.31	65.5^{c} ± 3.16	89.1^{ab} ± 5.29
L*	34.1^{c} ± 0.64	35.4^{b} ± 0.68	37.5^{a} ± 0.8	35.0^{bc} ± 0.47	32.3^{d} ± 0.67	32.5^{d} ± 0.57
a*	14.6^{a} ± 0.52	14.6^{a} ± 0.65	13.0^{b} ± 0.4	12.0^{b} ± 0.6	14.9^{a} ± 0.53	15.5^{a} ± 0.45
b*	11.6^{b} ± 0.38	12.9^{a} ± 0.54	12.9^{a} ± 0.29	10.6^{c} ± 0.33	11.1^{bc} ± 0.35	11.6^{b} ± 0.39
Chroma	18.6^{ab} ± 0.58	19.5^{a} ± 0.80	18.3^{b} ± 0.42	16.1^{c} ± 0.62	18.6^{ab} ± 0.61	19.4^{ab} ± 0.58
Hue-angle	38.6^{c} ± 0.95	41.5^{b} ± 0.77	44.8^{a} ± 0.83	41.8^{b} ± 1.04	36.6^{d} ± 0.57	36.6^{d} ± 0.49
Proximate analysis						
Moisture (%)	77.8^{a} ± 0.29	76.0^{b} ± 0.37	77.2^{a} ± 0.26	75.6^{b} ± 0.23	77.3^{a} ± 0.41	77.5^{a} ± 0.24
Protein (%)	20.3^{d} ± 0.27	22.4^{a} ± 0.35	21.3^{b} ± 0.25	23.0^{a} ± 0.26	21.2^{bc} ± 0.35	20.5^{cd} ± 0.25
IMF (%)	1.7^{a} ± 0.07	1.6^{b} ± 0.04	1.4^{c} ± 0.05	1.2^{d} ± 0.08	1.3^{cd} ± 0.09	1.6^{b} ± 0.05
Ash (%)	1.1^{a} ± 0.01	1.1^{a} ± 0.01	1.1^{a} ± 0.01	1.1^{a} ± 0.01	1.0^{b} ± 0.01	1.0^{b} ± 0.01

LSMean: least squares mean; SEM: standard error of the mean.
BF: *Biceps femoris*; SM: *Semimembranosus*; ST: *Semitendinosus*; LTL: *Longissimus thoracis et lumborum*; IS: *Infraspinatus*; SS: *Supraspinatus*.
$^{a-d}$ LSMeans with different superscripts within rows differ significantly at $P \leq 0.05$.





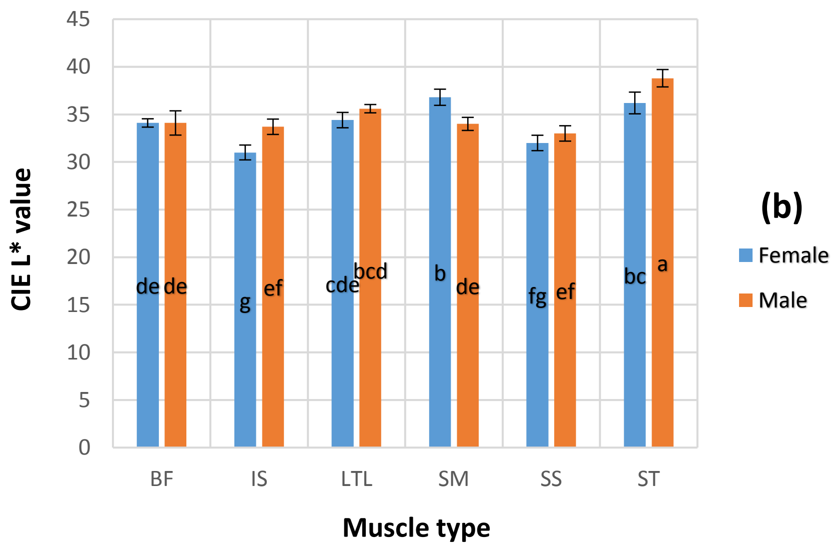


Figure 4.1 Interactions between sex and muscle type for the drip loss percentage (a), CIE L* (b) and b* (C) values.
BF: *Biceps femoris*; SM: *Semimembranosus*; SS: *Supraspinatus*; LTL: *Longissimus thoracis et lumborum*; IS: *Infraspinatus*; ST: *Semitendinosus*.
$^{a\text{-}g}$ LSMeans (within a main effect) with different superscripts differ significantly at $P \leq 0.05$.

4.5 Discussion

4.5.1 Physical analysis

All of the muscles had a pH_u that fell within the acceptable range of 5.6 to 5.8 (Immonen & Puolanne, 2000). The IS had the highest pH_u of 5.9 which is still acceptable since muscles are classified as dark, firm and dry (DFD) when the pH_u (24 hours *post-mortem*) is above six. The IS did however show signs of DFD since it had the lowest CIE L* value (darker colour), the lowest Warner-Bratzler shear force and the lowest cooking loss percentage (Barnier et al., 1992; Warris, 2000). Besides the IS, there was one animal in particular that had high pH_u values for four of the six muscles tested. Animal five's (male) BF (pH_u = 6.49), SM (pH_u = 6.23), IS (pH_u = 6.60) and SS (pH_u = 6.36) muscles could all be classified as DFD because of the high pH_u values and similar characteristics to the above mentioned IS muscle. This is likely the cause of ante-mortem stress in the form of prolonged antagonistic pressure from other bulls (male five was one of the smaller bulls) or rapid glycogen depletion before death since this animal was shot twice, covering a significant distance between the first and second shot and Hoffman (2000) has shown that stress resulting from a wound causes acute *ante-mortem* stress.

The drip loss percentages were generally less than what has been found for game meat previously. Although Neethling & Hoffman (2014) found a similar drip loss percentage for the SM of blesbok (*Damaliscus pygargus phillipsi*), their SM was still ranked lowest for drip loss in this smaller antelope species whereas the eland SM had the highest drip loss percentage. This could possibly be due to the fact that this muscle is known to have a high percentage of glycolytic fibres or white fibres. These fibres are characterized by a high glycolytic capacity and normally higher levels of glycogen activity which will lead to an increased rate of *post-mortem* pH decrease and a lower ultimate pH (Den Hertog-Meischkel et al., 1997). Lower ultimate pH together with higher rates of pH decline have previously been linked with increases in drip loss percentage (Lawrie & Ledward, 2006a). A higher drip loss could therefore be expected for the eland SM muscle as it had the lowest pH of the six muscles. Fitzhenry et al. (2016) also found in fallow deer (*Dama dama*) that the BF and IS muscles had the lowest drip loss percentage, but their ST had the highest drip loss whereas the eland ST was also ranked as one of the lowest for drip loss percentage. Bartoň and colleagues (2014) recorded the same drip loss percentage for eland LTL which was also similar for the cattle used in their comparison trial.

The SM showed further increases in moisture loss due to its low pH_u as it also had the highest cooking loss percentage of the six muscles. Therefore it can be expected that the SM meat may be perceived as dry and tough (Warriss, 2000a). The IS had the highest ultimate pH and as mentioned and showed signs of DFD development. The high pH_u of this muscle could also be the result of an increased rate of glycolysis due to the fact that it is located deeper within the carcass and consequently cools down slower (Lawrie & Ledward, 2006a). This slower cooling rate is exasperated by the fact that eland have large hindquarters (Chapter 3). The same was found in other studies comparing the muscles of fallow deer (Fitzhenry et al., 2016) and blesbok (Neethling & Hoffman, 2014).

According to Purchas and Aungsupakorn (1993), the tenderness of meat decreases from a pH of 5.5 up to a minimum close to a pH of 6.0 and then the tenderness starts to increase again as the pH increases. The reason for this curvilinear relationship is not yet fully understood, but it has been suggested that proteolytic activity is less between a pH of 5.8 – 6.3 and calpain activity rises to a maximum from pH six to seven (Purchas & Aungsupakorn, 1993). The higher tenderness of the IS could be explained by the pH preference of the above mentioned tenderization processes together with less moisture loss. Although not investigated in this study, the muscle fibre size and overall muscle texture could also contribute to higher toughness or tenderness. The SM is a coarse grained muscle with larger fibre diameters and bundles as most of the growth in this muscle takes place post-natal (Hoffman et al., 2009). Thus muscles with these characteristics will have a higher shear force compared to fine-grained muscles such as the ST and IS. This could potentially aid in explaining why the LTL muscle had the highest shear force rating. Also, the technique of determining the WBSF requires that visible connective tissue be avoided when taking the samples, and therefore even though these two muscles are small and have a tough epimysium, this is not included in the samples sheared. Furthermore, the LTL had the lowest intramuscular fat and moisture contents of all the muscles, which has previously been linked with tenderness (Hawkins et al., 1987). Neethling and Hoffman (2014) and Hoffman et al. (2009) found that for blesbok and kudu the LTL was ranked second toughest out of the same six muscles evaluated in their trial. Olsson et al. (1994) found that the LTL showed a greater reduction in shear force after ageing compared to other muscles, as was also found in the ageing trial of the LTL and BF (Chapter 6).

Collagen content and insolubility is known to increase with age as cross-links between poly-peptide chains become more thermally stable (Bailey, 1972). Furthermore collagen content and composition is known to vary between different skeletal muscles according to their placement and level of activity (Bendall, 1967; Lawrie & Ledward, 2006). Skeletal muscles differ in their activity levels due to their anatomical location as well as the manner in which they are used on a daily basis, therefore the activity level of various skeletal muscles will also vary between different game species, resulting in composition differences as well as quality of the final meat (Neethling & Hoffman, 2014). It could therefore be postulated that game species that are regular jumpers will have higher levels of collagen in the muscles involved when performing a jump. This would include the LTL muscle for flexing the spine during high vertical jumps together with those on the hind limbs used in the take-off action. The eland is renowned for its jumping ability and has been known to clear fences of up to two meters high (Flack, 2013). A higher content of collagen in these muscles together with decreased solubility at a mature age could lead to increases in toughness. This could potentially explain why the LTL was rated as the toughest with the BF at second toughest out of the six major muscles although the age aspect warrants further research as the eland bulls were all young animals.

Von La Chevallerie (1972) found that the eland LTL had the lightest colour of the seven ungulates examined in his study. This is positive since game meat is generally characterised by L* values below 40, high a* values and low b* values (Volpelli et al., 2003) which are indicative of the dark red colour which is regarded as unpopular amongst consumers (Hoffman, 2001). The undesired dark red colouring is usually linked with DFD meat as was the case with the IS muscle. Due to the high pH of DFD meat the oxidation of Mb is reduced, increasing colour stability (Faustman & Cassens, 1990; Ledward, 1985). However with increased colour stability comes the unwanted darker colour together with decreased shelf-life as the higher pH encourages microbial growth (Lawrie & Ledward, 2006c; Shange et al., 2018). The lowest ranking muscle for lightness (L*) was the IS, which was expected since it showed slight signs of DFD development. However the IS's CIE L* value of 32.3 is still considerably high in comparison to the low values that have been measured for smaller game such as impala, blesbok, springbok and fallow deer (Fitzhenry et al., 2016; Hoffman, Kroucamp, & Manley, 2007; Hoffman et al., 2009; Neethling & Hoffman, 2014). As with fallow deer, impala and kudu, the ST was also ranked highest for lightness. The ST has previously been reported to contain higher levels of glycolytic fibres (type IIB) which primarily metabolize glycogen and have very few mitochondria (O'Keeffe & Hood 1982; Renerre & Labas, 1987). These muscles thus have a very limited oxidative capacity which reduces discolouration when exposed to oxygen.

In a study on muscle fibre and meat characteristics between intensive vs. extensive beef, Vestergaard et al. (2000) found that physical activity of the animals had a greater influence on the meat colour than the diet. Increased physical activity led to an increase in oxidative fibres and the SS was identified as having a high proportion of type I (slow-twitch oxidative) muscle fibres. Due to the high amount of mitochondria and oxidative capacity the myoglobin (Mb) content is also higher in the SS giving it a redder appearance. The same was found for eland as well as other game such as kudu, impala and fallow deer (Fitzhenry et al., 2016; Hoffman et al., 2009). The eland LTL had the lowest CIE a* value which is in agreement with previous studies on game, but the LTL of beef is generally lighter in colour with a slightly higher a* value (Bartoň et al., 2014; Bureš et al., 2015; Vermaak, 2006). The LTL's a* value was however still above the cut-off point of 12 which Wiklund and colleagues (2001) established as the minimum a* value for consumer acceptance. The LTL had the highest saturation of all the muscles, but this value together with the low a* and b* values indicate that the LTL will have a greyer, pinkish colour that is more defined. Beef muscles normally don't differ with more than a 10° hue-angle, whereas pork muscles can differ by as much as 35° (Jones, 1995). The difference between the highest and lowest ranking muscles in this study for hue-angle was less than 10°, and the mean hue-angle was almost in the middle of the red and yellow light spectrum, but slightly more towards a red hue.

4.5.2 Proximate analysis

Proximate composition for game species generally range from 70 – 75 g/100 g for the moisture content, 20 – 24 g/100 g for the protein content, 0.2 – 2.5 g/100 g for the IMF content and 1.0 – 2.4 g/100 g for the ash content (Hoffman & Cawthorn, 2013; Keeton & Eddy, 2004; Neethling & Hoffman, 2014). The muscles that were analysed had similar compositions to the ranges specified above, except for the moisture content that varied from 75.6 – 77.8

g/100 g (Table 4.2). Sex did not have any influence on the proximate composition of eland meat. Generally females have higher fat compositions than males (Lawrie & Ledward, 2006b), but the differences are rarely significant. Sex was also not an influencing factor in the proximate composition of kudu, blesbok and black wildebeest (Hoffman et al., 2009; Hoffman et al., 2008; Hoffman et al., 2009).

The proximate composition of various South African game species as well as domestic animals is depicted in Table 4.2. All results were obtained from raw samples of the LTL muscles of these species and are divided between sexes where possible.

Game animals tend to have a higher moisture percentage than domestic animals due to a higher ratio of metabolically active tissue to fatty tissue (Aidoo & Haworth, 1995). The low level of intramuscular fat in game meat increases the cell density which may further affect the levels of moisture, protein and sodium. Although the LTL was ranked as having the lowest moisture (together with the SM) of the six muscles tested, it still had the highest moisture out of all the game species listed, most probably due to the fact that the eland in this study also had the lowest LTL fat content (Table 4.2). The other four muscles did not differ significantly from each other, but the highest moisture content was more than two percent higher than was measured for the LTL (Table 4.2), indicating that eland meat has a fairly high moisture content compared to other game meats.

The highest protein content was measured in the LTL followed by the SM, indicating some relationship between moisture and protein content (Table 4.2). Generally an inverse relationship exists between the IMF and moisture content (Doornenbal & Murray, 1982; Keeton & Eddy, 2004; Lawrie & Ledward, 2006a), but due to the lack of IMF in game species (Table 4.2)(Van Schalkwyk & Hoffman, 2016) there is often a stronger negative correlation between moisture and protein content, as was the case for blesbok (Neethling & Hoffman, 2014). The higher protein to fat ratio of game species compared to domestic species makes it an excellent source of nutrients since it provides the diet with essential amino acids and proteins of high biological value.

Von La Chevallerie (1972) found that eland meat had the highest fat percentage out of the seven game species that he evaluated. The results in Table 4.2 suggests otherwise, however this can be expected since factors such as season, location and experimental sample size differ between the individual trials. It should also be noted that the eland in this specific trial were harvested during an extended drought and it would thus be expected that their condition would be poor. Even within the same location, the IMF can change from one season to the next due to factors such as rainfall and temperature having an influence on the plane of nutrition and activity levels of animals (Neethling & Hoffman, 2014). It is interesting to note that Bartoň and colleagues (2014) found that bull eland meat from the LTL contained only 0.2 % fat, despite being fed a mixed diet based on maize, lucerne silages and cereal straw. This is contradictory to what is expected for intensively reared animals receiving this type of diet, especially since the activity levels of these eland are limited to a two to three hectare enclosure. One plausible explanation is that this diet was standardised for cattle heifers, which should have less intensive metabolism than eland (Taylor & Lyman, 1967), and therefore could be less nutritious for elands resulting in lower IMF. However the method of lipid extraction could also have influenced the final amount detected since some extraction methodologies cannot remove the phospholipids which are present in higher ratios when lipid levels are low. Higher activity levels of most game species combined with their natural grazing and browsing diets have been reported to decrease the fat levels of these species (Hoffman & Wiklund, 2006). The same has been found for beef grazing on pasture compared to being fed a concentrate diet (Realini et al., 2004). The average fat content of most game species has been recorded to be less than 3 % (Table 4.2) (Hoffman & Wiklund, 2006). Hoffman et al. (2015) found that eland cows had a significantly higher total fat content that bulls, but this value was still low compared to domestic species (Table 4.2). The free range production methods utilized on South African game farms together with the low fat content of the meat makes it an attractive product for health conscious consumers.

Table 4.2 Proximate composition of *Longissimus thoracis et lumborum* muscles from male and females of selected game and domestic species in South Africa (adapted from Hoffman & Cawthorn, 2013).

	Scientific name	Moisture (%)		Protein (%)		Fat (%)		Ash (%)		Reference
		F	M	F	M	F	M	F	M	
Game species										
Eland	*Tragelaphus oryx*	76.6	77.1	21.6	21.2	1.48	1.45	1.1	1.1	Present study
Eland	*Tragelaphus oryx*	73.3	74.1	23.4	24.1	2.1	1.2	1.1	1.1	Hoffman et al., 2015
Springbok	*Antidorcas marsupialis*	65.3	65.8	30.6	30.8	3	2.6	1.3	1.4	North & Hoffman, 2015
Blesbok	*Damaliscus dorcas phillipsi*	75.02	75.12	22.31	22.39	1.14	0.76	1.29	1.26	Smit, 2004
Red Hartebeest	*Alcelaphus buselaphus caama*	74.75	75.08	23.1	23.34	2.81	4.69	1.22	1.16	Smit, 2004
Fallow deer	*Dama dama*	73.4	74.2	22.7	22.6	3	2.5	1.1	1.1	Fitzhenry et al., 2016
Kudu	*Tragelaphus strepsiceros*	75.77	75.66	22.25	22.77	1.49	1.48	1.19	1.22	Hoffman et al., 2009a
Impala	*Aepyceros melampu*	74	74.96	23.07	22.63	2.4	2.06	1.16	1.22	Hoffman et al., 2009b
Mountain reedbuck	*Redunca fulvorufula*	72.59	72.76	24.51	23.68	2.43	2.94	1.22	1.23	
Black wildebeest	*Connochaetes gnou*	75.21	74.69	20.73	19.42	1.13	0.97	1.25	1.29	van Schalkwyk, 2004
Blue wildebeest	*Connochaetes taurinus*	75.99	75.55	22.83	23.31	1.38	1.26	1.38	1.26	
Domestic species										
Beef (Aberdeen Angus)	*Bos taurus*	–	72.85	–	21.41	–	3.62	–	2.12	Bureš et al., 2015
Lamb (Dorper/merino)	*Ovis aries*	70.1		17.8		11.3		2.65		Van Heerden et al., 2007
Pork	*Sus scrofa domesticus*	74.4		22.3		2.3		1.2		Barbieri et al., 2004

F: Female; M: Male

4.6 Conclusion

Eland meat compares favourably to meat from domestic species regarding its physical attributes. For the physical measurements, differences were generally not large, but the SM had higher values for all of the physical measurements except shear force and CIE lightness (L*), most probably linked to this muscle having the lowest pH_u. The IS on the other hand had the highest pH_u and ranked lowest for most of the physical measurements except the CIE a* and b* values, this is similar to what is expected for DFD meat. The LTL had the highest shear force but the lowest fat and moisture content, supporting the fact that higher fat and moisture contents can improve tenderness. However the BF which had the highest fat content was ranked second toughest, thus at low levels as measured in eland meat there is little to no correlation between the IMF and decreased shear force.

Differences in certain physical attributes among muscles might influence the processing quality as well as visual and sensory acceptance among consumers. Therefore different muscles should be processed and marketed according to their physical characteristics to obtain the maximum value for the carcass. As expected, the proximate analysis revealed a low fat content, however the moisture content was slightly above what has been recorded for other game species and subsequently the protein content was slightly lower than for most of the species listed. No significant differences between females and males were apparent for any of the chemical composition variables measured, however differences exist between the six muscles that were used in the trial. Although the muscles differed significantly in their proximate composition, the percentage difference between the highest and lowest ranked muscles for each measurement never exceeded three percent. These small differences indicate that eland muscles are generally similar in terms of nutrient value to humans. Overall results indicate that eland meat need not be marketed according to sex and that it has a competitive edge above domestic meat since it is leaner and of natural origin.

4.7 References

Aidoo, K. E., & Haworth, R. J. (1995). Nutritional and chemical composition of farmed venison. *Journal of Human Nutrition and Dietetics*, 8, 441–446.

Bailey, A. J. (1972). The basis of meat texture. *Journal of the Science of Food and Agriculture*, 23, 995–1007.

Barbieri, G., Pizza, A., & Gianni, C. (2004). Relationship between physical and chemical attributes of beef and pork muscles and processing suitability. *Italian Journal of Food Science*, 16, 59–68.

Barnier, V. M. H., Geesink, G. H., Smulders, F. J. M., & Van Logtestijn, J. G. (1992). Rate of glycolysis, chilling rate and beef quality: an inventory of potential consequences. In 38th International Congress of Meat Science Technology. Clermont-Ferrand, France.

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. *Meat Science*, 96, 346–352.

Bureš, D., Bartoň, L., Kotrba, R., & Hakl, J. (2015). Quality attributes and composition of meat from red deer (*Cervus elaphus*), fallow deer (*Dama dama*) and Aberdeen Angus and Holstein cattle (*Bos taurus*). *Journal of the Science of Food and Agriculture*, 95, 2299–2306.

Charles, A. B., King, J. M., & Heath, B. R. (1981). Game domestication for animal production in Kenya: an analysis of growth in oryx, eland and zebu cattle. *The Journal of Agricultural Science*, 97, 453–463.

Den Hertog-Meischkel, M. J. A., Van Laack, R. J. L. M., & Smulders, F. J. M. (1997). The water-holding capacity of fresh meat. *Veterinary Quarterly*, 19, 175–181.

Doornenbal, H., & Murray, A. C. (1982). Effects of age, breed, sex and muscle on certain mineral concentrations in cattle. *Journal of Food Science*, 47, 55–58.

Dransfield, E. (2001). Consumer issues and acceptance of meat. 47th International Congress of Meat Science and Technology (pp.72-79). Krakouw, Poland.

Dransfield, E. (2003). Consumer acceptance – meat quality aspects. In Consistency of quality 11th International Meat Symposium (pp. 146-159). Pretoria, South Africa.

Faustman, C., & Cassens, R. G. (1990). The biochemical basis for discoloration in fresh meat: a review. *Journal of Muscle Foods*, 1, 217–243.

Fitzhenry, L., Hoffman, L. C., Cawthorn, D. M., & Muchenje, V. (2016). Yields and Meat-Quality attributes of wild Fallo deer (*Dama dama*) in South Africa. Master's Thesis, Stellenbosch University.

Flack, P. (2013). *Hunting the Spiral Horns: Eland, Everyman's Elephant*. Johannesburg: Rowland Ward Publications.

Hawkins, R. R., Davis, G. W., Cable, J. K., & Ramsey, C. B. (1987). Fragmentation index as an early post-mortem predictor of beef tenderness. *Journal of Animal Science*, 64, 171–176.

Hoffman, L. C. (2000). Meat quality attributes of night-cropped Impala *(Aepyceros melampus*). *South African Journal of Animal Sciences*, 30, 133–137.

Hoffman, L. C. (2001). The effect of different culling methodologies on the physical meat quality attributes of various game species. In H. Ebedes, B. Reily, W. Van Hoven, & B. Penzhorn (Eds.), Proceedings of the 5th International Wildlife Ranching Symposium Sustainable Utilization - Conservation in practice (pp. 212–221). Pretoria, South Africa.

Hoffman, L. C., & Cawthorn, D. (2013). Exotic protein sources to meet all needs. *Meat Science*, 95, 764–771.

Hoffman, L. C., Kroucamp, M., & Manley, M. (2007). Meat quality characteristics of springbok (*Antidorcas marsupialis*). 1: Physical meat attributes as influenced by age, gender and production region. *Meat Science*, 76, 755–761.

Hoffman, L. C., Mostert, A. C., Kidd, M., & Laubscher, L. L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science*, 83, 788–795.

Hoffman, L. C., Smit, K., & Muller, N. (2008). Chemical characteristics of blesbok (*Damaliscus dorcas phillipsi*) meat. *Journal of Food Composition and Analysis*, 21, 315–319.

Hoffman, L. C., Van Schalkwyk, D. L., McMillin, K. W., & Kotrba, R. (2015). Intramuscular fat characteristics of Namibian common eland (*Tragelaphus oryx*). *African Journal of Wildlife Research*, 45, 312–320.

Hoffman, L. C., Van Schalkwyk, S., & Muller, N. (2009). Effect of season and gender on the physical and chemical composition of black wildebeest (*Connochaetus gnou*) meat. *South African Journal of Wildlife Research*, 39, 170–174.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison - meat for the modern consumer. *Meat Science*, 74, 197–208.

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, 49, 447–457.

Immonen, K., & Puolanne, E. (2000). Variation of residual glycogen-glucose concentration at ultimate pH values below 5.75. *Meat Science*, 55, 279–283.

Jones, S. M. (1995). *Quality and grading of carcasses of meat animals*. Florida: CRC Press.

Keeton, J. T., & Eddy, S. (2004). Chemical and physical characteristics of meat: Chemical composition. In W.K. Jensen, C. Devine & M. Dikeman (Eds), *Encyclopedia of meat sciences* (pp. 210–218). Oxford: Elsevier/Academic Press.

Lawrie, R. A., & Ledward, D. A. (2006a). Chemical and biochemical constitution of muscle. In *Lawrie's Meat Science* (pp. 75–127). Cambridge: Woodhead Publishing Limited.

Lawrie, R. A., & Ledward, D. A. (2006b). Factors influencing the growth and development of meat animals. In *Lawrie's Meat Science* (pp. 15–40). Cambridge: Woodhead Publishing Limited.

Ledward, D. A. (1985). Post-Slaughter Influences on the formation of metmyoglobin in beef muscles. *Meat Science*, 15, 149–171.

Neethling, J., & Hoffman, L. C. (2014). Impact of season on the chemical composition of male and female blesbok (*Damaliscus pygargus phillipsi*) muscles. *Journal of the Science of Food and Agriculture, 94, 424-431.*

Ngapo, T. M., & Dransfield, E. (2005). British consumers preferred fatness levels in beef: Surveys from 1955, 1982 and 2002. Food Quality and Preference, 17, 412–417.

North, M. K., & Hoffman, L. C. (2015). Changes in springbok (*Antidorcas marsupialis*) *Longissimus thoracis et lumborum* muscle during conditioning as assessed by a trained sensory panel. *Meat Science*, 108, 1–8.

Olsson, U., Hertzman, C., & Tornberg, E. (1994). The Influence of Low temperature, type of muscle and electrical stimulation on the course of rigor mortis, ageing and tenderness of beef muscles. *Meat Science*, 37, 115–131.

Purchas, R. W., & Aungsupakorn, R. (1993). Further Investigations into the relationship between ultimate pH and tenderness for beef samples from bulls and steers. *Meat Science*, 34, 163–178.

Realini, C. E., Duckett, S. K., Brito, G. W., Dalla Rizza, M., & De Mattos, D. (2004). Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. *Meat Science*, 66, 567–577.

Shapiro, S. S., & Wilk, M. B. (1965). An analysis of Variance Test for Normality (complete samples). *Biometrika*, 52, 591–611.

Smit, K. (2004). Meat quality characteristics of blesbok (*Damaliscus dorcas phillipsi*) and red hartebeest (*Alcelaphus buselaphus caama*) meat. Doctoral dissertation, Stellenbosch University.

Taylor, C. R., Lyman, C. P. (1967). A comparative study of environmental physiology of an East African antelope eland and Hereford steer. *Physiological Zoology*, 40, 280–295.

Van Heerden, S. M., Schönfeldt, H. C., Kruger, R., & Smit, M. F. (2007). The nutrient composition of South African lamb (A2 grade). *Journal of Food Composition and Analysis*, 20, 671–680.

Van Schalkwyk, D. L., & Hoffman, L. C. (2016). *Guidelines for the harvesting & processing of wild game in Namibia*. Republic of Namibia, Ministry of Environment & Tourism.

Van Schalkwyk, S. (2004). Meat quality characteristics of three South African game species: Black wildebeest (*Connochaetes gnou*), Blue wildebeest (*Connochaetes taurinus*), Mountain reedbuck (*Redunca fulvorufula*). Master's tesis, Stellenbosch University.

Vermaak, A. (2006). Enhancement of beef by means of infusing a phosphate and lactate blend. Doctoral dissertation, Stellenbosch University.

Vestergaard, M., Oksbjerg, N., & Henckel, P. (2000). Influence of feeding intensity, grazing and finishing feeding on muscle fibre characteristics and meat colour of *semitendinosus*, *longissimus dorsi* and *supraspinatus* muscles of young bulls. *Meat Science*, 54, 177–185.

Volpelli, L. A., Valusso, R., Morgante, M., Pittia, P., & Piasentier, E. (2003). Meat quality in male fallow deer (*Dama dama*): effects of age and supplementary feeding. *Meat Science*, 65, 555–562.

Von La Chevallerie, M. (1972). Meat quality of seven wild ungulates. *South African Journal of Animal Sciences*, 2, 101–103.

Warriss, P. D. (2000). Meat quality. In *Meat Science: An Introductory Text* (pp. 106–130). Wallingford: CAB International Publishing.

Wiklund, E., Stevenson-Barry, J. M., Duncan, S. J., & Littlejohn, R. P. (2001). Electrical stimulation of red deer (*Cervus elaphus*) carcasses - effects on rate of pH-decline, meat tenderness, colour stability and water-holding capacity. *Meat Science*, 59, 211–220.

Chapter 5: Influence of sex and muscle type on the sensory qualities of common eland (*Tragelaphus oryx)* meat

5.1 Abstract

This trial investigated the sensory attributes of eland meat as well as the fatty acid profile to gain a better understanding of how a trained panel would rate the meat and how the fatty acid profile would influence this rating. The overall aroma intensity recorded for eland was high (68.3 out of 100) and was strongly correlated ($r = 0.926$) to beef-like aroma. Unwanted aroma and flavour attributes such as gamey (19.9 and 18.3 out of a 100 for flavour and aroma, respectively), livery (1.3 and 1.2) and metallic (5.1 and 9.6) did not play a significant role in the overall profile of the meat. The discriminant analysis plot showed a clear distinction between male and female LTL's, while the BF's were grouped closer together. Overall the BF (72 and 68 for aroma and flavour intensity, respectively) was rated higher for aroma and flavour than the LTL (65.5 and 62.7); this was supported by the variable loadings plot showing a stronger association with the BF than LTL for most of the sensory attributes. The BF also had higher amounts of most fatty acids (17.94 mg/g total fatty acids, compared to 12.36 for the LTL), possibly linked to a higher intramuscular fat. The fatty acid profile for eland was very promising since the P:S ratio was between 0.4 and 0.6, with the bulk of the saturated fatty acids (SFA) being made up of stearic acid (around 78 % of the SFA's). The n-6:n-3 ratio was also lower (1.01-1.77) than recorded previously for this species, further supporting the fact that free range game can be considered as a healthier alternative to intensively farmed livestock.

5.2 Introduction

In 2050 the world population is estimated to pass the nine billion mark. If food production has not increased by 50% we are destined to follow in the footsteps of some of the African countries that have failed to feed their people (Ericksen et al., 2009). The African continent has always been the centre of focus when it comes to issues regarding malnourishment (Bain et al., 2013; FAO, 2013). The continent's demand for food resources, especially quality protein sources can potentially be met by the use of indigenous game species to replace or contribute to the domestic meat market in areas that face production challenges such as an adverse climate (Lindsey, 2011; Mossman & Mossman, 1976). These species are naturally adapted to their respective habitats and therefore the environmental footprint and expenses of such an enterprise would be lower compared to farming with less adapted domestic livestock (Cole, 1990). Also, live sales, ecotourism, trophy and recreational hunting are all potential sources of additional income when farming with game animals (Hoffman, 2007).

While red meat is highly valued as a means to decrease malnutrition and improve food security in developing countries (McNeill & Van Elswyk, 2012), consumers in developed countries associate red meat with health problems (Wilcox et al., 2009) related to high fat and cholesterol contents (Higgs, 2000). Game meat is considered to be an attractive alternative to traditional red meats, because of its leanness, exotic appeal and the fact that it can be marketed as “free range” and “eco-friendly” (Hoffman & Wiklund, 2006). Eland meat is reported to have a lower intramuscular fat content (2 g/kg) than beef (von La Chevallerie, 1972), while the proportion of essential fatty acids is high (Cordain et al., 2002). The fatty acid content of meat is important to human health, specifically the ratio of polyunsaturated fatty acids (PUFA) to SFA (Higgs, 2000). However the ratio of n-6/n-3 polyunsaturated fatty acids is of equal importance since high levels of the omega-6 PUFA’s can have negative effects on the health of human consumers (Dransfield, 2001). High levels of PUFA’s have been recorded for various game species as well as high P:S and low n-6:n-3 ratios (Hoffman & Wiklund, 2006); eland in Namibia had a PUFA to SFA ratio of 4-5 and a n-6:n-3 ratio between 2.7 and 2.9 (Hoffman et al., 2015).

The meat industry has managed to maintain a fairly consistent quality standard with regards to producing products from domestic animals that are similar in terms of appearance, nutritional and sensory quality. This is however not always the scenario in the game meat industry which is still developing slaughter regulations, cropping techniques, etc. and is not as established as the domestic meat industry. Furthermore there is little control over ante-mortem factors that play a significant role in the final quality of the meat. These factors include microbiological safety, ethical and consistent harvesting procedures, healthiness and sensory attributes. Sensory attributes of meat, which includes the visual perception of the product before buying, is regarded as very important by consumers when buying meat. These attributes include the visual appearance as well as the texture, tenderness, juiciness, aroma, taste and flavour when consuming the cooked product. Game meat is characterized by a low fat and high protein content, this together with incorrect cooking methods often result in negative perceptions of dry and tough meat. Most game meat is also described as having a distinct wild animal flavour which is not always enjoyed by all, especially female consumers. Despite these negative associations, game meat has proven itself to be a healthy source of nutrients and therefore it is important to research and optimize the sensory attributes if consumer satisfaction is to be guaranteed.

Little scientific output exists regarding the meat characteristics of game species, especially pertaining to the sensory attributes between species. This is especially of interest with the common eland whose meat is said to be comparable to beef in taste and aroma, while being healthier to consume (Mossman & Mossman, 1976). Therefore the purpose of this study was to investigate the sensory characteristics of common eland meat. The *Longissimus thoracis et lumborum* (LTL) and *Bicep femoris* (BF) muscles were cooked and presented to a trained panel, who used descriptive sensory analysis to determine the overall sensory quality of the meat. These results together with physical measurements that were taken from the cooked samples were used to compare sexes and muscles.

5.3 Materials and methods

5.3.1 Harvest and slaughter

Twelve (six male, six female) eland were harvested on the Prinskraal farm near Bredasdorp in the Western Cape Province of South Africa. Harvesting took place in accordance with the standard operating procedure (ethical clearance number: 10NP_HOF02). Animals were harvested on two separate occasions within the period of one month between the months of June and July 2016. After a kill shot to the head or chest, the animals were exsanguinated and transported to the slaughtering facilities to be skinned and eviscerated. Carcasses were quartered before being suspended in a cold truck (0-5 °C) for transportation back to the meat processing lab at the Department of Animal Sciences at the University of Stellenbosch. See Chapter 3 for more detail.

5.3.2 Sampling

Carcasses were transferred to a cold room (2-4 °C) upon arrival at the department and were processed the following day (day two after death). Both sections of the LTL muscle was removed from the front and hind quarters as well as the BF muscle from the hind quarters. The left muscles were used for this sensory trial and proximate analysis, while the right muscles were further divided for the purpose of an ageing trial (Chapter 6). Both muscles were trimmed of subcutaneous fat and epimysium and then cut in half, one part was used for the training phase of the sensory trial and the other for the descriptive analysis testing while a small steak was cut from the middle of the muscle for the purpose of proximate analysis. Specific attention was given to assure that the portions were similar in size and from the same anatomical position of each muscle for each of the twelve carcasses. Thus a total of four portions per carcass were obtained for the chemical and sensory analyses and subsequently vacuum-packed. These portions were then placed back in the cold room to age for another week to develop flavour and aroma. After the brief ageing was completed all the samples were transferred to a freezer and frozen at –20 °C until analysis was done ten weeks later.

5.3.3 Sample preparation

Samples were removed from the freezer 24 h prior to preparation to be thawed at 5.4 ± 0.60 °C in the cold room. On the day of testing, the samples were removed from their bags, dried with paper towels, weighed and placed in separate oven bags (Glad®) for cooking. The samples were prepared according to the method described by Geldenhuys, Hoffman, and Muller (2014), with the exception of cooking the meat until an internal temperature of 75 °C was reached, where after the meat was rested for 10 minutes. Samples were then cut into steaks and further cut into 1 x 1 x 1 cm cubes and wrapped in tinfoil. Prior to testing the wrapped cubes of meat was placed back in the oven at 70 °C for ten minutes for reheating. Samples were then transferred to water baths set at 70 °C to maintain their heat throughout the training and testing sessions (AMSA, 1995).

5.3.4 Descriptive sensory analysis

A panel of 12 members was chosen to perform the descriptive sensory analysis (DSA) in the sensory lab at the Department of Food Science at Stellenbosch University. All members had previous experience with analysis of various meat products and were trained in accordance with the guidelines described by AMSA (1995) and Lawless and Heymann (2010). Training was done by giving the panellists three blocks of meat from both muscles of each animal together with nine reference samples to compare to (Table 5.1). By using the reference samples as a baseline measure, eight aroma descriptors, eight flavour descriptors and five textural descriptors were decided upon (Table 5.2). Testing commenced after all panel members were confident and clear about the descriptors that were decided upon. The 12 animals were randomly assigned to one of six sessions that took place over the course of three days. A ten point line scale was used to evaluate the various attributes of each sample by using the test re-test method described by Geldenhuys et al. (2014).

5.3.5 Physical analysis

5.3.5.1 pH

After complete thawing of the testing portions the pH was recorded for all the samples in the trial. This was done by using a calibrated (pH standard buffers at pH 4.0 and pH 7.0) Crison ICRI2502 portable pH meter.

5.3.5.2 Cooking loss

Following pH measurements, the samples were cut into the appropriate sizes, blotted dry with paper towels and weighed to obtain the raw weight. They were then cooked and rested (as described in section 5.3.3) and weighed once more to obtain the final cooked weight. The moisture lost during cooking was expressed as a percentage of the raw weight (AMSA, 1995).

5.3.5.3 Warner Bratzler shear force

In order to compare what the panel perceived as tough or tender the instrumental toughness was measured by means of a Warner Bratzler shear force (WBSF) test (Honikel, 1998). The meat that remained after the test cubes for the descriptive analysis had been cut was stored in a fridge (5.4 ± 0.60 °C) for 24 h. Six test blocks were cut out of a 2 cm thick steak in such a way that the muscle fibres ran parallel to the longitudinal axis of the 1 x 1 x 2 cm block. The shear force was measured using an Instron Universal Testing Machine (Instron UTM, Model 2519–107) that cut perpendicularly through the longitudinal muscle fibres. The Warner Bratzler blade had a triangular opening leading into a half circle (radius of 0.508 mm) cutting blade of 1 mm thickness. This blade was attached to a crosshead travelling at 200 mm/min through the sample. After cutting all six samples, the average was calculated to determine the Warner Bratzler shear force (N).

5.3.6 Chemical analysis

5.3.6.1 Fatty acid content

The fatty acid (FA) profiles of the LTL and BF muscles from each eland carcass were determined independently. The samples were prepared and fatty acid methyl esters (FAME) were extracted as described by Fitzhenry and colleagues (2016) except that the initial raw weight of eland meat used was one gram. Following the extraction of the FAME they were analysed using a Thermo Scientific TRACE 1300 series gas-chromatograph (Thermo Electron Corporation, Milan, Italy) equipped with a flame-ionisation detector, using a 30 m ZB-FAME capillary column with an internal diameter of 0.25 mm and a 0.20 µm film (Cat. No. 7HG-G033-10-GGA, Zebron, Phenomenex) and a run time of ca. 30 mins. The following oven temperature settings were used: initial temperature of 100 °C (maintained for two min) and final temperature of 260 °C attained after three ramps (initial increase at a rate of 10 °C/min until a temperature of 140 °C was reached; thereafter an immediate increase at a rate of three °C/min to reach 190 °C where after the temperature was increased at a rate of 30 °C/min to reach 260 °C and maintained this temperature for a minimum of five min. The injector temperature was set at 260 °C and the detector temperature at 260 °C. The hydrogen gas flow rate was 40 mL/min. The FAME of each sample was identified by comparing the retention times with those of a standard FAME mixture (Supelco™ 37 Component FAME mix, Cat no. 47885-U, Supelco, USA), with results being expressed as mg fatty acid/g meat or as a percentage of the total fatty acids.

Table 5.1 Reference samples that were used during the training phase of the descriptive sensory analysis of eland.

Reference sample	Reference for	Final internal temperature	Scale
Beef liver	Liver-like aroma & flavour	No probe	0 = low intensity; 100 = high intensity
Beef fat	Fatty aroma & flavour	No probe	0 = low intensity; 100 = high intensity
Beef shin	Toughness	No probe	0 = tough; 100 = extremely tender
Beef fillet	Tenderness, residue	72 °C	0 = tough; 100 = extremely tender
Free range beef rump (35 days matured)	Roasted beef-like aroma & flavour	75 °C	0 = low intensity; 100 = high intensity
Chicken breast	Initial & sustained juiciness	75 °C	0 = dry; 100 = extremely juicy
Chicken breast overdone	Initial & sustained dryness, mealiness	85 °C	0 = dry; 100 = extremely juicy
Ostrich moon steak	Metallic aroma & flavour	75 °C	0 = low intensity; 100 = high intensity
Springbok loin	Gamey aroma & flavour	75 °C	0 = low intensity; 100 = high intensity

Table 5.2 Description and scale of the sensory attributes (aroma, flavour and texture) decided upon by the trained panel.

Sensory attribute	Description	Scale
Aroma		
Overall Intensity	Intensity of aroma in first few sniffs	0 = low intensity; 100 = high intensity
Beef-like	Aroma associated with cooked beef rump	0 = low intensity; 100 = high intensity
Gamey	Aroma associated with meat from wild animal species – sometimes a combination of liver-like and metallic aromas	0 = low intensity; 100 = high intensity
Buttery	Aroma associated melted butter	0 = low intensity; 100 = high intensity
Sweetcorn	Aroma associated with tinned sweetcorn	0 = low intensity; 100 = high intensity
Metallic	Aroma associated with raw meat or blood	0 = low intensity; 100 = high intensity
Liver-like	Aroma associated with pan fried beef liver	0 = low intensity; 100 = high intensity
Fatty	Aroma associated with melted fat	0 = low intensity; 100 = high intensity
Sour	Aroma associated with expired meat or milk	0 = low intensity; 100 = high intensity
Flavour		
Overall intensity	Intensity of flavour after first few chews	0 = low intensity; 100 = high intensity
Beef-like	Flavour associated with cooked beef rump	0 = low intensity; 100 = high intensity
Gamey	Flavour associated with meat from wild animal species – sometimes a combination of liver-like and metallic flavours	0 = low intensity; 100 = high intensity

Table 5.2 Continued

Buttery	Flavour of salted butter, associated with roasted beef	0 = low intensity; 100 = high intensity
Sweetcorn	Flavour associated with tinned sweetcorn	0 = low intensity; 100 = high intensity
Metallic	Flavour associated with raw meat or blood	0 = low intensity; 100 = high intensity
Livery	Flavour associated with pan fried liver	0 = low intensity; 100 = high intensity
Fatty	Flavour associated with pan fried beef fat	0 = low intensity; 100 = high intensity
Sour	Taste associated with a citric acid solution	0 = low intensity; 100 = high intensity
Texture		
Initial juiciness	Amount of fluid extruded on surface of meat when pressed between thumb and forefinger (perpendicular to fibres)	0 = extremely dry; 100 = extremely juicy
Sustained juiciness	Amount of moisture perceived during mastication	0 = extremely dry; 100 = extremely juicy
Tenderness	Impression of tenderness after mastication	0 = extremely tough; 100 = extremely tender
Residue	Residual tissue remaining after mastication (difficult to chew through)	0 = none; 100 = prominent
Mealiness	Disintegration of muscle fibres into very small particles (perception within the first few chews)	0 = none; 100 = prominent

5.3.7 Statistical analysis

A completely random split plot design was used for the experimental design with sex as the main plot factor and muscle types as the subplot factors. In total six males and six females were randomly assigned to one of six testing sessions where their two muscle samples (LTL and BF) were evaluated.

Panellists' results were monitored with PanelCheck Software (Version 1.4.0, www.panelcheck.com) and their reliability was then tested by subjecting the data to test-retest analysis of variance (ANOVA) using the GLM (General Linear Models) procedure in SAS™ statistical software (Statistical Analysis System, Version 9.4, SAS Institute Inc., Cary, NC, USA). Together with this, the data was tested for non-normality using the Shapiro-Wilk test.

Using XLSTAT® (Version 2014.2.03; Addinsoft, New York, USA) associations between the sensory attributes and the physical measurements were illustrated by means of Principal Component analysis (PCA) and Discriminant Analysis (DA).

5.4 Results

In Table 5.3 the level of statistical significance is shown for the effect of sex, muscle as well as interaction between the two on the physical measurements and sensory attributes. The average, minimum and maximum values are also represented in the table. None of the attributes with the exception of Sweetcorn aroma ($P = 0.058$) and Metallic aroma ($P = 0.005$) showed significant interactions, thus the main effects are discussed further.

Neither sex nor muscle had an influence on the physical measurements (Table 5.3). Of the two main effects (sex and muscle), the two muscles used had a significant influence on most of the sensory attributes (Table 5.6). Only sweetcorn aroma and metallic aroma were influenced by the interaction between sex and muscle (Table 5.4). Sweetcorn aroma differed ($P \leq 0.05$) between the female LTL (13.0 ± 0.80) and BF (17.0 ± 0.66) muscles, but there was no difference between female or male muscles. The male BF was significantly different in metallic flavour to the rest of the groups explaining the interaction between the main effects.

The BF muscle had a higher ($P \leq 0.0001$) overall aroma intensity than the LTL (Table 5.3). Beef-like and gamey aroma were higher ($P \leq 0.01$ and $P \leq 0.05$, respectively) for the BF (Table 5.3) as was buttery and sweetcorn aroma ($P \leq 0.0001$ and $P \leq 0.05$, respectively). The overall flavour intensity was scored higher ($P \leq 0.01$) for the BF than the LTL. The scores for beef-like, buttery and sweetcorn flavour were all higher ($P \leq 0.01$ for all) in the BF. Gamey, livery and fatty flavours were also more distinct ($P \leq 0.05$ for all) for the BF.

Sex influenced the overall flavour, beef-like flavour and gamey flavour of the meat (Table 5.5). All of the flavour attributes were scored slightly higher for cows than for bulls.

Animal nine's (bull) LTL was identified as an outlier but was included in the Principal Component Analysis (PCA) and Discriminant Analysis (DA) plots. A PCA bi-plot which demonstrates the correlation between the different sensory attributes and physical measurements for the two muscles of the males and females used in the testing is illustrated in Figure 5.1. The combination of PC1 and PC2 explained 51.7% of the total variance of which PC1 explained 26.9% and PC2 explained 24.7%. The discriminant loadings plot (Fig. 5.2a) illustrates the discrimination of the attributes and its association with the different treatments indicated in the DA plot (Fig. 5.2b). The DA plot shows that the treatments are separated. The combination of PC1 and PC2 explains 99.7% of the total variance of which PC1 and PC2 explained 93.1% and 6.6%, respectively.

The fatty acid profiles (%) of female and male eland as well as the BF and LTL muscles are shown in Tables 5.7 and 5.8, respectively. There was no interaction between sex and muscle type for any of the fatty acids analysed. Sex influenced the amount of palmitic, archidic, α-linolenic, eicosadienoic and total saturated fatty acids. Muscle type on the other hand had an influence on palmitic, stearic, archidic, lignosteric, palmitoleic, erucic, linoleic, α-linolenic and eicosadienoic acids as well as the total amount of SFA, MUFA, PUFA, *n*-6 PUFA, *n*-3 PUFA and the SFA:PUFA and *n*-6:*n*-3 ratios. These results were further used to calculate correlations between sensory attributes and selected fatty acids.

Table 5.3 Level of statistical significance (*P* - values) for the main effects of sex and muscle and their interaction as well as the LSMeans (± SEM), minimum and maximum values of the physical measurements and sensory attributes of eland meat.

	Sex	Muscle	Sex x Muscle	LSMean	Minimum	Maximum
Physical measurements						
pH	0.378	0.302	0.284	5.6 ± 0.04	5.4	6.4
Cooking loss %	0.754	0.838	0.139	36.4 ± 0.58	26.0	42.5
WBSF (N)	0.765	0.481	0.629	76.1 ± 5.6	37.0	156.0
Sensory attributes						
Overall Aroma Intensity	0.100	**≤0.001**	0.695	68.7 ± 0.91	61.2	76.2
Beef-like Aroma	0.064	**0.004**	0.382	62.3 ± 0.79	56.0	70.5
Gamey Aroma	0.833	**0.012**	0.211	19.9 ± 0.42	16.1	23.6
Buttery Aroma	0.827	**≤0.0001**	0.440	18.7 ± 0.58	13.5	24.2
Sweetcorn Aroma	0.966	**0.014**	**0.058**	15.0 ± 0.56	10.3	20.1
Metallic Aroma	0.475	0.119	**0.005**	5.1 ± 0.52	1.5	12.2
Livery Aroma	0.322	0.066	0.075	1.3 ± 0.23	0.0	3.3
Fatty Aroma	0.090	0.497	0.856	10.1 ± 0.04	10.0	10.5
Sour Aroma	0.315	0.282	0.339	0.6 ± 0.11	0.0	1.7
Overall Flavour Intensity	**≤0.001**	**0.001**	0.765	65.4 ± 0.74	59.1	72.3
Beef-like Flavour	**0.012**	**0.003**	0.810	62.4 ± 0.65	57.1	70.7
Gamey Flavour	**0.024**	**0.050**	0.198	18.3 ± 0.50	13.6	23.4
Buttery Flavour	0.667	**0.006**	0.874	16.8 ± 0.59	10.1	24.2
Sweetcorn Flavour	0.910	**0.003**	0.869	12.4 ± 0.48	7.8	18.6
Metallic Flavour	0.443	0.249	0.419	9.6 ± 0.50	5.5	14.9
Livery Flavour	0.401	**0.054**	0.693	2.2 ± 0.37	0.0	6.7
Fatty Flavour	0.899	**0.028**	0.116	10.1 ± 0.05	9.6	10.5
Initial Juiciness	0.444	0.389	0.399	35.6 ± 1.40	20.5	46.9
Sustained Juiciness	0.650	0.487	0.643	34.1 ± 1.26	26.3	51.2
Tenderness	0.227	0.580	0.934	37.8 ± 1.51	27.0	53.2
Residue	0.280	0.730	0.618	37.2 ± 1.27	20.1	46.8
Mealiness	0.795	0.099	0.421	10.1 ± 1.10	2.3	23.9

Table 5.4 Influence of the interaction between the main effects of sex and muscle on the sweetcorn and metallic aroma of eland meat (LSMeans ± SEM).

Aroma attribute	Female		Male		*P*-value
	BF	LTL	BF	LTL	
Sweetcorn Aroma	17.0^{a} ± 0.66	13.0^{b} ± 0.80	15.3^{ab} ± 0.78	14.6^{ab} ± 1.59	0.058
Metallic Aroma	4.1^{a} ± 0.50	5.0^{b} ± 0.50	6.9^{b} ± 0.50	4.2^{b} ± 0.50	0.005

LSMeans: least squares mean; SEM: standard error of the mean.

$^{a-b}$ LSMeans within a variable/attribute with different superscripts differ significantly from one another.

Table 5.5 Influence of sex on the gamey flavour of eland meat (LSMeans ± SEM).

Flavour attribute	Sex		*P*-value
	Female	Male	
Overall Flavour intensity	66.6 ± 0.97	64.2 ± 1.04	≤0.001
Beef-like Flavour	63.5 ± 0.84	61.4 ± 0.94	0.012
Gamey Flavour	19.4 ± 0.62	17.3 ± 0.69	0.024

LSMeans: least squares mean; SEM: standard error of the mean.

Table 5.6 Influence of muscle on some of the flavour and aroma attributes of eland meat (LSMeans ± SEM).

Sensory attribute	Muscle		
	BF	LTL	*P*-value
Overall Aroma Intensity	72.0 ± 0.91	65.5 ± 0.84	≤ 0.0001
Beef-like Aroma	64.8 ± 1.03	59.9 ± 0.67	0.0035
Gamey Aroma	21.0 ± 0.42	18.9 ± 0.59	0.0120
Buttery Aroma	21.2 ± 0.40	16.2 ± 0.37	≤ 0.0001
Sweetcorn Aroma	16.1 ± 0.55	13.8 ± 0.88	0.0139
Overall Flavour Intensity	68.0 ± 0.57	62.7 ± 0.83	0.0013
Beef-like Flavour	64.5 ± 0.71	60.3 ± 0.68	0.0033
Gamey Flavour	19.3 ± 0.47	17.4 ± 0.82	0.0504
Buttery Flavour	18.5 ± 0.69	15.1 ± 0.70	0.0063
Sweetcorn Flavour	13.8 ± 0.63	10.9 ± 0.42	0.0033
Livery Flavour	2.9 ± 0.56	1.5 ± 0.43	0.0535
Fatty Flavour	10.2 ± 0.06	10.0 ± 0.07	0.0275

LSMeans: least squares mean; SEM: standard error of the mean.

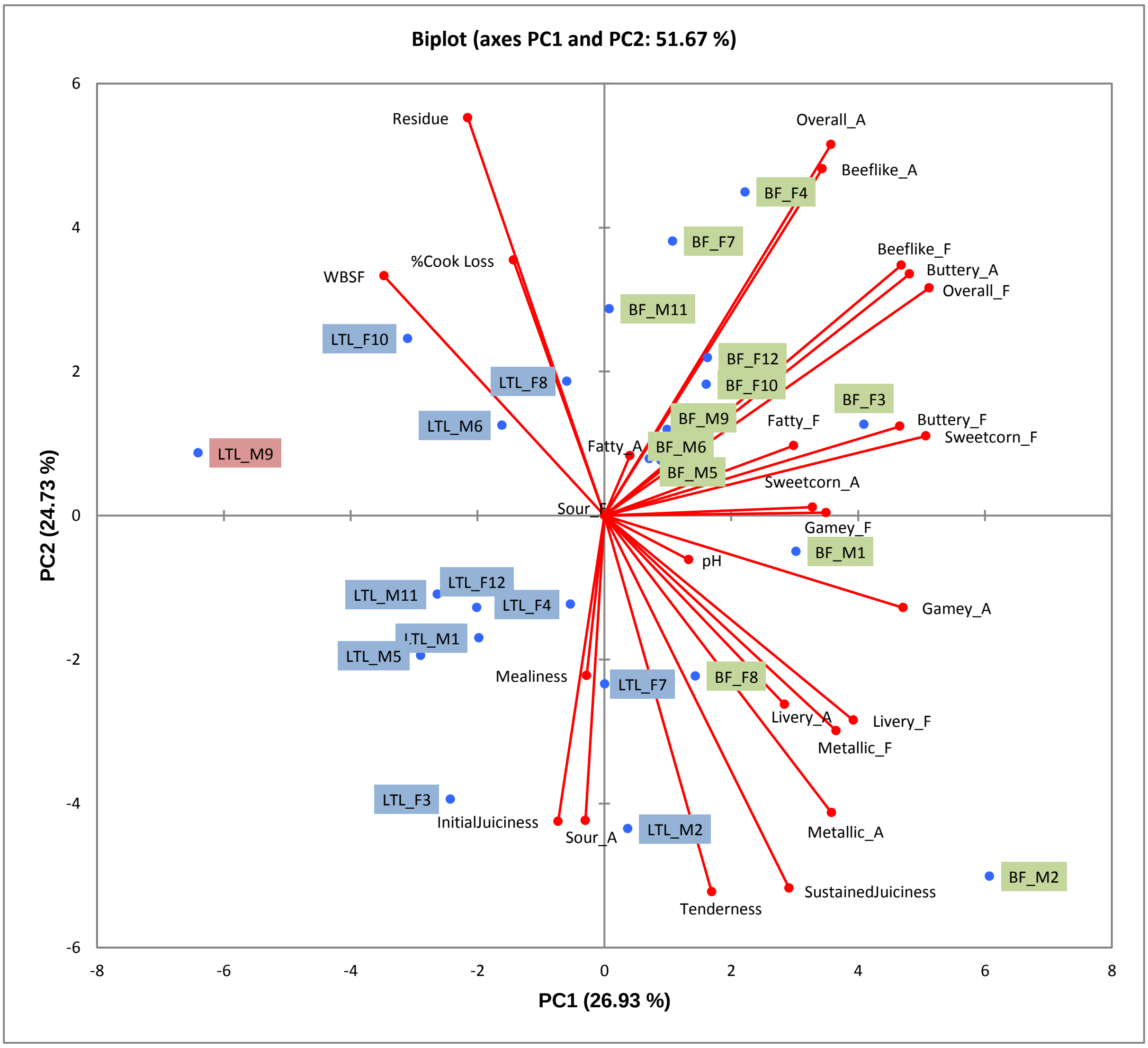


Fig. 5.1 Principal component analysis (PCA) bi-plot indicating the means of the sensory attributes and physical characteristics of eland meat. The letters “A” and “F”, following the attribute descriptors refer to aroma and flavour and attributes without a letter are either textural attributes or physical measurements. The outlier (LTL male 9) is highlighted in red and the rest of the LTL muscles are highlighted in blue and BF muscles in green. The sex is indicated with either an “F” or “M” for female and male, respectively before the animal number.

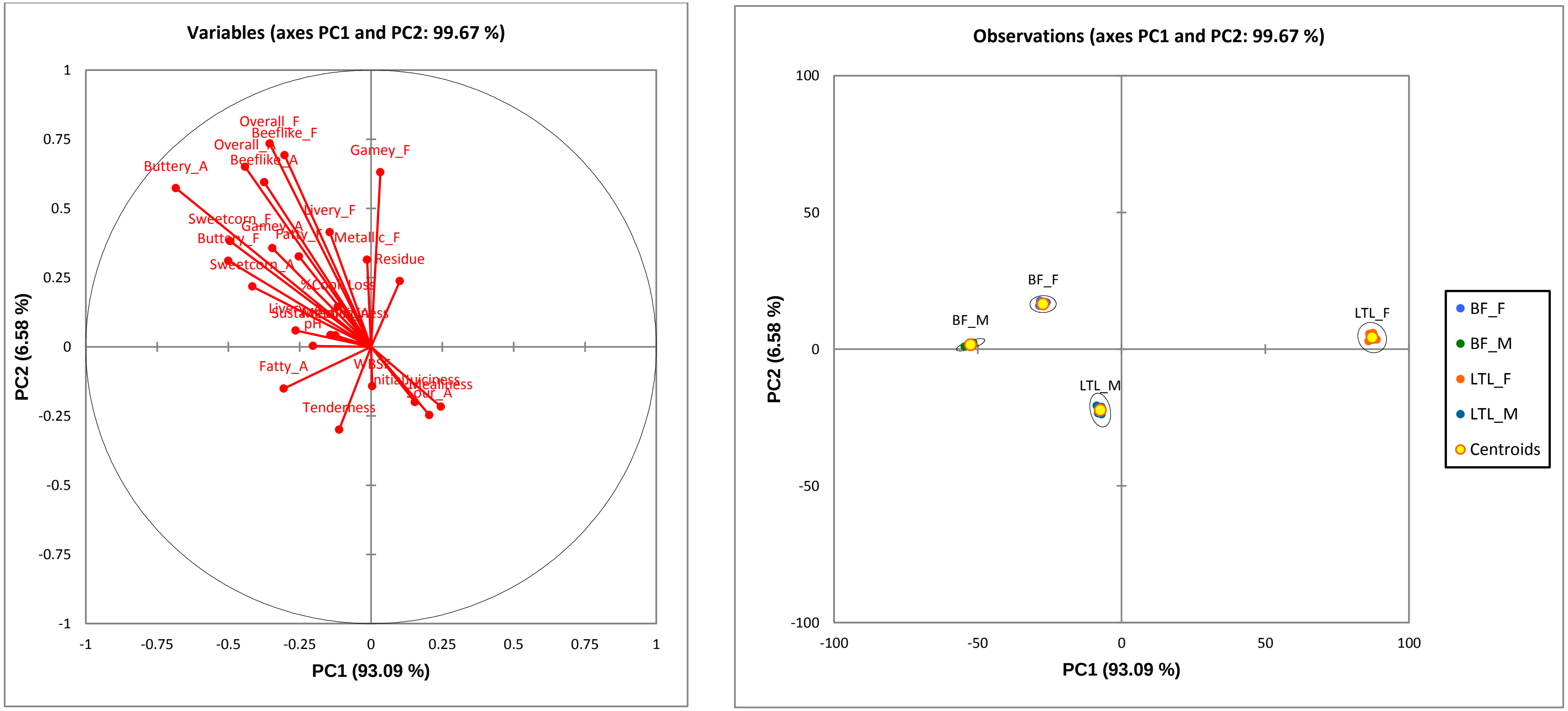


Fig. 5.2 DA variable loadings plot (a) and Discriminant analysis (DA) plot (b) of the sensory attributes and physical characteristics of eland meat. The letters "A" and "F", following the attribute descriptors refer to aroma and flavour and attributes without a letter are either textural attributes or physical measurements. The letters "F" and "M" following the muscle groups refer to male and female, respectively.

Table 5.7 The fatty acid profile (%) (LSMeans ± SEM) for both sexes and the *Longissimus thoracis et lumborum* (LTL) and *Bicep femoris* (BF) muscles of eland.

	Sex		***P* - value**	**Muscle**		***P* - value**
	Females	**Males**		**BF**	**LTL**	
SFA	62.71 ± 2.82	72.03 ± 1.46	0.0721	64.71 ± 2.56	70.03 ± 2.48	**0.0106**
C13:0 (Tridecylic)	0.01 ± 0.01	0.04 ± 0.02	0.0798	0.04 ± 0.02	0.01 ± 0.01	0.2609
C14:0 (Myristic)	0.11 ± 0.07	0.07 ± 0.04	0.8058	0.15 ± 0.07	0.03 ± 0.02	0.1804
C15:0 (Pentadecylic)	0.32 ± 0.09	0.24 ± 0.04	0.708	0.33 ± 0.09	0.23 ± 0.05	0.2144
C16:0 (Palmitic)	0.23 ± 0.04	0.31 ± 0.03	**0.0186**	0.35 ± 0.03	0.19 ± 0.02	**0.0047**
C18:0 (Stearic)	48.65 ± 2.83	55.48 ± 1.94	0.1789	47.68 ± 2.41	56.45 ± 2.15	**0.0015**
C20:0 (Arachidic)	8.60 ± 0.36	10.98 ± 0.33	**0.0003**	10.56 ± 0.43	9.02 ± 0.45	**0.0002**
C21:0 (Heneicosylic)	ND	ND	ND	ND	ND	ND
C22:0 (Behenic)	ND	ND	ND	ND	ND	ND
C23:0 (Tricosylic)	ND	ND	ND	ND	ND	ND
C24:0 (Lignoceric)	4.80 ± 0.37	4.92 ± 0.37	0.98	5.62 ± 0.27	4.10 ± 0.21	**<0.0001**
MUFA	0.52 ± 0.04	0.56 ± 0.03	0.3561	0.62 ± 0.02	0.47 ± 0.03	**0.0045**
C16:1 (Palmitoleic)	0.19 ± 0.02	0.19 ± 0.02	0.7233	0.24 ± 0.01	0.14 ± 0.02	**0.0028**
C18:1 n-9t (Vaccenic)	ND	ND	ND	ND	ND	ND
C18:1 n-9c (Oleic)	ND	ND	ND	ND	ND	ND
C20:1 (Gondoic)	0.19 ± 0.01	0.20 ± 0.02	0.9114	0.17 ± 0.02	0.22 ± 0.02	0.0655
C22:1 n-9 (Erucic)	0.15 ± 0.02	0.18 ± 0.03	0.2548	0.21 ± 0.01	0.11 ± 0.02	**0.0056**
C24:1 (Nervonic)	ND	ND	ND	ND	ND	ND

Table 5.7 continued

PUFA	36.77 ± 2.82	27.40 ± 1.44	0.0715	34.67 ± 2.55	29.50 ± 2.48	**0.0114**
C18:2 *n*-6c (Linoleic)	15.27 ± 0.82	14.39 ± 0.68	0.7364	15.61 ± 0.77	14.05 ± 0.69	**0.0302**
C18:2 *n*-6t (Linolelaidic)	ND	ND	ND	ND	ND	ND
C18:3 *n*-3 (α-Linolenic)	17.76 ± 2.21	8.67 ± 0.70	**0.0238**	14.56 ± 2.11	11.87 ± 2.03	**0.0365**
C18:3 *n*-6 (γ-Linolenic)	ND	ND	ND	ND	ND	ND
C20:2 *n*-6 (Eicosadienoic)	2.05 ± 0.16	2.73 ± 0.24	**0.0445**	2.82 ± 0.18	1.96 ± 0.14	**<0.0001**
C20:3 *n*-3 (Eicosatrienoic ; ω-3)	ND	ND	ND	ND	ND	ND
C20:3 *n*-6 (Eicosatrienoic; ω-6)	ND	ND	ND	ND	ND	ND
C20:4 *n*-6 (Arachidonic)	ND	ND	ND	ND	ND	ND
C20:5 *n*-3 (Eicosapentaenoic)	ND	ND	ND	ND	ND	ND
C22:2 *n*-6 (Docosadienoic)	0.37 ± 0.03	0.28 ± 0.02	0.0559	0.32 ± 0.03	0.33 ± 0.03	0.4716
C22:5 *n*-3 (Docosapentaenoic)	ND	ND	ND	ND	ND	ND
C22:6 *n*-3 (Docosahexaenoic)	1.32 ± 0.13	1.33 ± 0.07	0.8014	1.36 ± 0.10	1.29 ± 0.10	0.3331

LSMeans: least squares means; SEM: standard error of the mean; ND: not detected; c: cis; t: trans.
SFA: saturated fatty acids; MUFA: mono-unsaturated fatty acids; PUFA: poly-unsaturated fatty acids.

Table 5.8 Fatty acid totals and ratios (mg/g) (LSMeans ± SEM) for eland meat.

	Sex		*P* - value	Muscle		*P* - value
	Females	**Males**		**BF**	**LTL**	
Total fat	1.50 ± 0.11	1.53 ± 0.11	0.2113	1.79 ± 0.08	1.24 ± 0.07	**0.0020**
Total SFA	9.32 ± 0.66	10.93 ± 0.73	**0.0077**	11.68 ± 0.68	8.57 ± 0.48	**0.0110**
Total MUFA	0.08 ± 0.01	0.09 ± 0.01	0.1589	0.11 ± 0.01	0.06 ± 0.00	**0.0003**
Total PUFA	5.60 ± 0.65	4.28 ± 0.48	0.3146	6.15 ± 0.50	3.73 ± 0.49	**0.0007**
Total fatty acids	15.00 ± 1.05	15.30 ± 1.14	0.2113	17.94 ± 0.77	12.36 ± 0.74	**0.0020**
PUFA:SFA	0.62 ± 0.07	0.39 ± 0.03	0.0734	0.57 ± 0.07	0.44 ± 0.06	**0.0146**
n-6 PUFA	2.67 ± 0.24	2.71 ± 0.29	0.4332	3.33 ± 0.19	2.05 ± 0.19	**0.0002**
n-3 PUFA	2.93 ± 0.44	1.57 ± 0.20	0.0659	2.82 ± 0.38	1.68 ± 0.33	**0.0040**
n-6:*n*-3	1.01 ± 0.09	1.77 ± 0.07	0.0002	1.33 ± 0.11	1.45 ± 0.15	0.2153

LSMeans: least squares means; SEM: standard error of the mean.
SFA: saturated fatty acids; MUFA: mono-unsaturated fatty acids; PUFA: poly-unsaturated fatty acids.

5.5 Discussion

The final pH of a muscle can influence factors such as the water holding capacity (WHC), tenderness and flavour of the meat (Honikel, 2004a). The normal range for the pH_u (ultimate pH) of meat can range from 5.3 to 5.8 and is mostly influenced by stressful harvesting procedures that deplete muscle glycogen levels (Immonen & Puolanne, 2000). Only one of the muscles (BF of male animal five) used in this trial (N = 24) had an above normal pH_u value (pH = 6.4) which was expected to influence some of the sensory attributes as it did influence the physical measurements for this muscle. However the aroma, flavour and texture attributes were all similar to the rest of the samples except for the initial juiciness being slightly lower. The DFD (Dark, Firm, Dry) BF had a cooking loss percentage of 33.9 % (cooking loss % average for BF = 36.4 ± 0.62) which is expected of DFD meat since water is bound more tightly because of the firm muscle structure (Warriss, 2000b) and a WBSF reading of 38.8 N (WBSF average for BF = 73.4 N) which is also in line with what has been found for DFD beef in the past (Barnier et al., 1992; Dransfield, 1981; Viljoen et al., 2002), possibly related to an increase in calpain activity linked to the higher muscle pH (Beltran et al., 1997). However the rest of the muscles that were tested had pH values within the acceptable range (Table 3.4; mean pH = 5.6 for both LTL and BF), therefore the sex and muscle differences in the ratings for certain flavour and aroma attributes was not ascribed to pHu.

The meat used in this trial was frozen at -20 for approximately two months before the trial took place. This is also the case with most of the game meat in Southern Africa destined for export as this is normal protocol during air freight (Dahlan & Norfarizan Hanoon, 2008; Gonzalez-Sanguinetti et al., 1985). Water holding capacity is known to decrease after prolonged freezing because the myofibrillar structure is disrupted during ice crystal formation (Gonzalez-Sanguinetti et al., 1985; Leygonie et al., 2012). This would lead to an increase in thaw and cooking losses because water is released from the protein bonds and intracellular space to the extracellular space during protein denaturation. Mean cooking loss percentages for the two muscles used were higher (36.5 ± 0.62 and 36.4 ± 0.62 for the BF and LTL, respectively) after being frozen than was found for the fresh meat used in the muscle comparison trial (Chapter 4, Table 4.2). Although these values are higher than what has been reported in previous studies on eland (Bartoň et al., 2014), it is still in line with results from other studies on game meat (Hoffman et al., 2009; Hoffman et al., 2009; Neethling et al., 2014; Onyango et al., 1998). Cooking loss was negatively correlated to tenderness and mealiness (r = -0.614 and r = -0.666; $P \leq 0.001$), indicating that an increase in cooking losses would lead to a tougher sample but with less of a mealy mouth feel.

Warner Bratzler shear force (WBSF) values obtained for both muscles (73.4 ± 5.2 and 78.8 ± 5.2 N for the BF and LTL, respectively) were in line with previous findings for eland meat (Luděk Bartoň et al., 2014) and according to Destefanis et al. (2008) eland can be classified as being tough (WBSF > 52.68 N). Although neither sex nor muscle influenced the sensory tenderness of the meat (Table 5.3), the readings (LSMeans of 37.8 ± 1.51, minimum of 27.0 and maximum of 53.2) indicated that the panel used the lower end of the scale, indicating that they found the meat to be less tender. As expected, there was a strong negative correlation (r = -0.724; $P \leq 0.0001$) between the sensory tenderness and the WBSF values. The negative correlation is due to the fact that sensory tenderness is rated out of a 100 with zero being tough, whereas lower WBSF readings would be an indication of higher tenderness. A sample with a high (>50) sensory tenderness rating will therefore have a lower WBSF value (<40). Thus the WBSF reading can be used as a predictor, together with other measurements such as intramuscular fat content, as an indication of the sensory tenderness. Residue and cooking loss percentage scores were positively correlated (r = 0.747 and r = 0.728; $P \leq 0.0001$, respectively) to the WBSF readings indicating that tougher muscles would have higher levels of moisture loss during cooking as well as more perceived residue.

Beef-like aroma was the highest contributor to the overall aroma intensity (Table 5.3). This is indicated by the high intensity of beef-like aroma (62.3) relative to the overall aroma intensity (68.3) and gamey aroma (19.9) as well as the correlation found between beef-like aroma and overall aroma (r = 0.926; $P \leq 0.0001$). The BF had a higher ($P \leq 0.0001$) overall aroma intensity as well as a higher ($P \leq 0.01$) beef-like aroma compared to the LTL (Table 6.6). Bartoň and colleagues (2014) found that the eland LTL had a stronger odour than that of beef, this can be related to the gamey aroma attribute which has previously been positively correlated to overall aroma intensity in game meat (Neethling et al., 2016). Buttery aroma was positively correlated to beef-like aroma as well as the overall aroma intensity (r = 0.769 and r = 0.826; $P \leq 0.0001$, respectively). Buttery aroma was moderately correlated (r = 0.500; $P = 0.013$) to sweetcorn aroma, but buttery flavour was highly correlated (r = 0.911; $P \leq 0.0001$) with sweetcorn flavour. However, both gamey aroma and buttery aroma which can be classified as negative attributes, were scored on the lower end of the scale (Table 5.3).

Gamey aroma was characterised as a combination of liver-like and metallic aromas which were both moderately correlated (r = 0.495 and r = 0.470; $P \leq 0.05$, respectively) with gamey aroma. This correlation has been found in blesbok meat as well (Neethling et al., 2016) and is regarded as unfavourable since liver-like and metallic aromas are unwanted sensory attributes (Yancey et al., 2006). Gamey aroma and flavour were both more intense ($P \leq 0.05$ for both) for the BF. Buttery aroma was scored equally as high as gamey aroma for the BF and can thus be regarded as an important influence on the overall aroma. Metallic aroma was influenced by the interaction between sex and muscle (Table 5.4) and was slightly higher than what was previously reported for beef (Rødbotten et al., 2004). Other game animals have been reported to have stronger metallic and liver aromas (Geldenhuys et al., 2014; North & Hoffman, 2015). The BF had a stronger livery flavour than the LTL, but this correlates with other attributes such as gamey flavour and overall flavour intensity being higher (Table 5.6 and Fig. 5.2). Beef-like flavour was once again strongly correlated (r = 0.904; $P \leq 0.0001$) to the overall flavour intensity and buttery flavour was again scored similarly to gamey flavour as was the case with the aromas (Table 5.6).

Sex only influenced three of the flavour attributes, all being higher for the cows (Table 5.5). Cows had a more intense overall flavour ($P \leq 0.001$) and because of the strong correlations with beef-like flavour and gamey flavour (r = 0.904 and r = 0.615, $P \leq 0.0001$ and $P \leq 0.001$, respectively), these two attributes were also significantly higher for females. Gamey flavour was also found to be higher for springbok females (North & Hoffman, 2015). This attribute was reported to be influenced by a high polyunsaturated fatty acid (PUFA) content which is promoted by low levels of fat and a browser diet (Lawrie & Ledward, 2006a). Game animals have been reported to have higher levels of PUFA's (Hoffman, 2007) adding to the gamey flavour and thus overall flavour intensity.

The DA plot (Fig. 5.2b) clearly shows a separation between groups on the horizontal axis of the plot and the fact that none of the ellipses overlap indicates that treatments were not similar in terms of sensory and physical qualities. BF muscles for both sexes are grouped closely together in the top left quadrant while male LTL's where placed in the bottom left quadrant and female LTL's all the way to the right in the top quadrant. The discriminant loadings plot (Fig. 5.2a) illustrates the discrimination of the attributes and its association with the different treatments indicated in the DA plot (Fig. 5.2b). Along PC1 the BF muscles for males and females were associated with overall aroma, buttery aroma and flavour and sweetcorn aroma and flavour. Separation of female BF's from the male group (along PC2) is driven by overall aroma and flavour as well as beef-like and gamey flavour. Male LTL's are separated from the rest of the treatments primarily because of the influence of textural characteristics such as tenderness, initial juiciness and mealiness, but sour aroma also caused separation. Female LTL's showed the most separation from the rest of the treatments along PC1 with mealiness, sour aroma, initial juiciness and residue being the main drivers for this separation. The same trends can be seen on the PCA bi-plot (Fig. 5.1), where the LTL and BF muscles are clearly separated along PC1.

It should be noted that the meat samples used for FAME extraction and analysis contained very little intramuscular fat (1.50 ± 0.11 % and 1.53 ± 0.11 %, for females and males, respectively) as is the case with most game species which could have resulted in certain fatty acids not being detected, especially SFA's and MUFA's since they are mostly found in the triacylglycerol fraction of lipids within intramuscular fat deposits. Oleic acid (C18:1 *n*-9c) for example is normally more than double the amount of linoleic acid (C18:2 *n*-6c), however it was not detected as was the case for most of the SFA's and MUFA's only showing trace amounts within the sample. This resulted in the total percentage of MUFA's being very low compared to previous studies (Hoffman et al., 2015). Steric acid (C18:0) together with palmitic acid (C16:0) is normally the main SFA's in red meat (Higgs, 2000; Volpelli et al., 2003; Wiklund et al., 2003), however the percentage of steric acid was more than double than what was previously recorded for eland, this then led to the total percentage of SFA's also being higher than measured before (Hoffman et al., 2015). This despite the fact that the mg/g content of steric acid was in line with previous findings. The influence of intramuscular fat content on the amount of fatty acids was seen with the BF which had a higher fatty acid content than the LTL as well as a higher intramuscular fat content. Consequently the BF had more SFA's, MUFA's and almost double the amount of PUFA's than the LTL. The low fat content could possibly also explain why some of the fatty acids that are normally present in meat samples were not detected.

As mentioned, palmitic acid is normally found in red meats, however this SFA together with myristic acid (C14:0) has been flagged for increasing plasma cholesterol levels which is a risk for coronary heart disease (Ahrens et al., 1957; Sundram et al., 1994). Although the amount of palmitic acid was influenced by sex as well as muscle type, the percentages recorded were less than half a percent in all cases indicating that this fatty acid did not play a major role in the whole fatty acid profile of the eland used in this trial. Males had higher levels of palmitic acid which is the same as found previously, however the levels recorded in previous studies were significantly higher. Hoffman and colleagues (2015) recorded percentages of 20.2 % for males and 18.4 % for females, while palmitic acid was the most abundant (24.4 %) fatty acid in farmed eland males (Bartoň et al., 2014). Stearic acid was the most abundant fatty acid in eland meat and was significantly higher in the LTL compared to the BF (47.68 ± 2.41 % and 56.45 ± 2.15 %, respectively). Although the percentage of stearic acid is more than double what was recorded by Hoffman and colleagues (2015), who also found it to be the most abundant, it is regarded as being a desirable SFA since it is converted to oleic acid in the human body (Bender, 1992). It does therefore not have a detrimental effect on consumers as with some other fatty acids in this group. Stearic acid and other long chain SFA's such as arachidic acid have been found to be higher in lambs fattened on pasture compared to feedlot (Rowe et al., 1999). This could explain why the free grazing eland in this trial had higher levels of arachidic and lignoceric acid than was recorded previously. From Table 6.7 it can be concluded that SFA's make up the majority of the fatty acid profile of eland meat, however stearic acid was found in abundance and accounted for ~77 % of the SFA's with the above mentioned long chain SFA's making up another ~20 %. Thus the SFA's that are considered harmful to human health make up a very small percentage of the entire fatty acid profile of eland meat.

The MUFA's that were detected are all in accordance with previous research on eland meat, besides for the fact that no oleic acid was detected. This is unusual since oleic acid content has been found to be more than 20 % in previous studies on eland and was also the most abundant fatty acid in a few studies on wild animals and beef (Hoffman & McMillin, 2009; Purchas & Zou, 2008; Wiklund et al., 2001). [It should be noted that the same procedures were used in this study as that used by Hoffman et al. in their previous studies on game meat and oleic acid was identified during the running of the Standard used in this investigation.] Seeing that this fatty acid is usually the principal MUFA in meat samples (Higgs, 2000) it is not surprising that the total MUFA content of eland meat was so low. As with palmitoleic (C16:1) and erucic (C22:1 *n*-9) acid, the total MUFA content was slightly higher for the BF, however the percentages that were recorded for these two fatty acids and the total MUFA content were nominal compared to the whole profile.

Linoleic acid was overall the most abundant PUFA which is in agreement with previous research on eland (Bartoň et al., 2014; Hoffman et al., 2015) and other game animals such as black wildebeest (Hoffman & McMillin, 2009), kudu (Hoffman et al., 2009) and buffalo. However, females had α-linolenic acid (C18:3 n-3) as the most abundant fatty acid in their meat. Grazing animals normally have higher concentrations of α-linolenic acid compared to animals receiving a grain based diet, as this is one of the main fatty acids contained in grass species (Realini et al., 2004; Wood et al., 2008). Alpha-linolenic acid is the most important omega-3 fatty acid for human health and regular intake is recommended as it has a proactive effect on cardiovascular deterioration (Simopoulos, 1991). This fatty acid can be endogenously desaturated and then elongated to long-chain *n*-3 fatty acids (Razminowicz et al., 2006), i.e. eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA). This is particularly of importance since the latter long-chain PUFA's were either not detected or in very low amounts in the eland meat. Females had more than double the amount of α-linolenic acid than males, while the BF had a slightly higher concentration that the LTL. Eicosadienoic acid (C20:2 n-6) also differed between sex and muscles with a slightly higher concentration being noted in the BF and for males, although the concentration was relatively low compared to other PUFA's.

The polyunsaturated fatty acid to saturated fatty acid ratio (P:S) is an important guideline used to determine the health implications when consuming meat. The British Department of Health (1994) recommends a ratio of higher than 0.45 throughout the whole diet. While ruminants are known to consume PUFA's through the grasses they eat, a large proportion of these fatty acids are subject to microbial hydrogenation (saturation) in the rumen and consequently a low percentage remains to be incorporated into tissue lipids (Wood et al., 2008). The LTL's ratio is in line with this recommendation while the BF's ratio is well above it. As mentioned, stearic acid, which is a desirable fatty acid, made up more than three quarters of the total amount of SFA's. Therefore the ultimate P:S ratio in the human body after consuming eland meat can be considered as healthy if the conversion of stearic to oleic acid in the body is considered. Furthermore the P:S ratio for eland in this study is in line with previous studies (0.4-0.6), indicating a relatively consistent, healthy ratio for eland meat.

Although PUFA's are generally accepted to be healthier than SFA's, a distinction should be made between omega-3 and omega-6 PUFA's. During the breakdown of omega-6 PUFA's there is an increase in eicosanoids which are involved in immune responses such as inflammation and fever. Consequently the British Department of Health (1994) recommends that this ration should not exceed 4:1. The diet on which man evolved is said to have had a ration of around 1:1 whereas the ratio of the modern human diet is estimated to be between 10:1 and 20:1. It is thus clear that we lack omega-3 fatty acids in the diet and are subsequently at risk for developing coronary heart disease. The BF had more omega-6 PUFA's than the LTL as well as omega-3 fatty acids, however the *n*-6:*n*-3 ratio did not differ between the two muscles (Table 5.8). The *n*-6:*n*-3 ratio was significantly lower for females than males, because females had almost double the amount of omega-3 PUFA's, although this difference was not significant. Furthermore it is known that linoleic acid and α-linolenic acid are not interconvertible and compete for the rate-limiting Δ6-desaturase in the synthesis of long-chain PUFA's in the body (Simopoulos, 2002). The long chain fatty acids that would eventually be synthesized out of these shorter PUFA's would therefore depend on which of these were consumed in a higher concentration (Mcafee et al., 2010). Consuming meat from female eland could thus further benefit the system since they had similar linoleic acid percentages to their counterparts, but where males had almost half less α-linolenic acid compared to linoleic, females had more α-linolenic acid. The higher percentage of α-linolenic acid, which is an omega-3 fatty acid, is then expected to be converted to long chain n-3 PUFA's. Overall the ratios for both sexes were lower compared to previous studies (2.7-2.9 and 5.04) (Bartoň et al., 2014; Hoffman et al., 2015, respectively) and other game species such as kudu (2.29), black wildebeest (2.82) and springbok (3.28) (Hoffman & Wiklund, 2006), but similar to pasture finished beef (Muchenje et al., 2009; Purchas & Zou, 2008).

Only the fatty acids that were recorded as higher than one percent of the total fatty acids were used when calculating Pearson correlation coefficients as it is questionable if anything below this amount would have a significant influence on the flavour and aroma attributes. These included: stearic, arachidic, lignoceric, linoleic, α-linolenic, eicosadienoic and DHA acid. However out of this group, only lignoceric and eicosadienoic acid had moderate to high correlations with selected sensory attributes. Lignoceric acid had moderate correlations (0.4-0.6) with the overall aroma, gamey aroma, buttery aroma, beef-like flavour, gamey flavour, sweetcorn flavour, livery flavour and had a high correlation (0.680) with overall flavour. However the total amount of lignoceric acid in the meat was less that a milligram, which raises the question if this fatty acid would truly have an influence at all? Stearic acid on the other hand was the most abundant fatty acid (6.90-8.62 mg/g), but only showed negative correlations. Eicosadienoic acid showed correlations with overall aroma (0.499) and buttery aroma (0.672), but once again the amount of this fatty acid is minute. Alpha-linolenic acid has previously been linked to gamey aroma and flavour as well as metallic flavour in Egyptian geese (Geldenhuys et al., 2014), however there were no correlations with these attributes in the current study which is expected since they received low scores during sensory testing.

5.6 Conclusions

There was little influence of sex on the sensory quality of eland meat; muscle type however did influence various aroma and flavour characteristics. Beef-like aroma and flavour contributed mostly to the overall aroma and flavour, respectively. This together with the fact that gamey flavour and aroma was scored relatively low can be regarded as being positive towards consumer acceptance of eland meat. However high WBSF values, cooking loss percentages and low initial and sustained juiciness scores could prove otherwise. The BF muscle proved to be superior in aroma and flavour, while being slightly tenderer. This is surprising since the LTL is regarded as a muscle with higher value (mainly due to superior tenderness) in beef meat production, suggesting that this might not be the case for eland production. Interaction of sex and muscle had a minor influence on the attributes.

As for the fatty acid content there was little correlation between the most abundant fatty acids and sensory attributes, likely to do with the small amount of intramuscular fat in the meat. Moreover eland have a P:S ratio that is within the acceptable limits and a *n*-6:*n*-3 ratio that can be considered as very healthy. Sex did not have as much of an influence on the fatty acid profile as was the case with muscle type and no interactions between the main effects were present.

Consequently sex does not have to be taken into account when harvesting eland for meat production purposes, but a distinction must be made between muscles. It would also be worth investigating if any of the other six major muscles that were sampled (Chapter 4) had similar sensory qualities to what was found for the BF and LTL as this might help shift consumers perceptions of game meat. Another aspect that warrants further research is whether aging of these two major muscles (in this trial the muscles had only aged for seven days before being frozen prior to sensory analyses), would lead to an increase in tenderness as well as other sensory attributes that tend to increase with aging such as juiciness, flavour and aroma. In terms of the fatty acid profile it is known that different habitats and vegetation types are known to be responsible for variations in the fatty acid profiles of animals from the same species (Hoffman, van Schalkwyk, & Muller, 2009). Eland from this area tend to browse less and graze more as grass species cover most of the land, with a few fynbos species in certain parts. The fatty acid profile of eland found elsewhere in South Africa and Africa as a whole, would therefore be expected to differ than what was found in this study as did the eland from Namibia (Hoffman, 2015). This information on how different diets influence the fatty acid profile can then be used to formulate rations that optimize the absorption and formation of healthy fatty acids in an animal.

5.7 References

Ahrens, E. H., Insull, W., Blomstrand, R., Hirsch, J., Tsaltas, T. T., & Peterson, M. L. (1957). The influence of dietary fats on serum-lipid levels in man. *The Lancet*, 269, 943–953.

American Meat Science Association. (1995). Research guidelines for cookery, sensory evaluation and instrumental tenderness measurements of fresh meat. *National Live Stock and Meat Board*, Chicago.

Bain, L. E., Awah, P. K., Geraldine, N., Kindong, N. P., Sigal, Y., Bernard, N., & Tanjeko, A. T. (2013). Malnutrition in Sub - Saharan Africa: Burden, causes and prospects. *Pan African Medical Journal*, 15, 1–9.

Barnier, V. M. H., Geesink, G. H., Smulders, F. J. M., & Van Logtestijn, J. G. (1992). Rate of glycolysis, chilling rate and beef quality: an inventory of potential consequences. In 38th International Congress of Meat Science Technology. Clermont-Ferrand, France.

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. *Meat Science*, 96, 346–352.

Beltran, J. A., Jaime, I., Santolaria, P., Sanudo, C., Alberti, P., & Roncales, P. (1997). Effect of Stress-induced high post-mortem pH on protease activity and tenderness of beef. *Meat Science*, 45, 201–207.

Bender, A. E. (1992). Meat and meat products in human nutrition in developing countries. Vol. 556. Rome: FAO.

Cole, M. L. (1990). A farm on the wild side. *New Scientist*, 127, 62-65.

Cordain, L., Watkins, B. A, Florant, G. L., Kelher, M., Rogers, L., & Li, Y. (2002). Fatty acid analysis of wild ruminant tissues: evolutionary implications for reducing diet-related chronic disease. *European Journal of Clinical Nutrition*, 56, 181–191.

Dahlan, I., & Norfarizan Hanoon, N. A. (2008). Chemical composition, palatability and physical characteristics of venison from farmed deer. *Animal Science Journal*, 79, 498–503.

Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. *Meat Science*, 78, 153–156.

Dransfield, E. (1981). Eating quality of DFD beef. In D.E. Hood, P.V. Tarrant (Eds), *The problem of dark cutting in beef* (pp. 344-358). Berlin: Springer.

Ericksen, P. J., Ingram, J. S. I., & Liverman, D. M. (2009). Food security and global environmental change: emerging challenges. *Environmental Science & Policy*, 12, 373–377.

Food and Agriculture Organization of the United Nations. (2013). The State of Food Insecurity in the World. The multiple dimensions of food security. Rome FAO.

Fitzhenry, L., Hoffman, L. C., Cawthorn, D. M., & Muchenje, V. (2016). Yields and Meat-Quality attributes of wild Fallo deer (*Dama dama*) in South Africa. Master's Thesis, Stellenbosch University.

Geldenhuys, G., Hoffman, L. C., & Muller, M. (2014). Sensory profiling of Egyptian goose (*Alopochen aegyptiacus*) meat. *Food Research International*, 64, 25–33.

Gonzalez-Sanguinetti, S., Anon, M. C., & Calvelo, A. (1985). Effect of thawing rate on the exudate production of frozen beef. *Journal of Food Science*, 50, 697–700.

Higgs, J. D. (2000). The changing nature of red meat: 20 years of improving nutritional quality. *Food Science & Technology*, 11, 85–95.

Hoffman, L.C. (2007). The meat we eat: are you game? In: Inaugural lecture. Stellenbosch, Western Cape, South Africa.

Hoffman, L. C., & McMillin, K. W. (2009). Improving the meat quality of venison and other exotic game. In J. Kerry & D. A. Ledward (Eds.), *Improving the sensory and nutritional quality of fresh meat* (pp. 447–475). Cambridge: Woodhead Publishing Limited.

Hoffman, L. C., Mostert, A. C., Kidd, M., & Laubscher, L. L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science*, 83, 788–795.

Hoffman, L. C., Van Schalkwyk, D., McMillin, K. W., & Kotrba, R. (2015). Intramuscular fat characteristics of Namibian common eland (*Tragelaphus oryx*). African Journal of Wildlife Research, 45, 312–320.

Hoffman, L. C., van Schalkwyk, S., & Muller, N. (2009). Effect of season and gender on the physical and chemical composition of black wildebeest (*Connochaetus gnou*) meat. *South African Journal of Wildlife Research*, 39, 170–174.

Hoffman, L. C., & Wiklund, E. (2006). Game and venison – meat for the modern consumer. *Meat Science*, 74, 197–208.

Honikel, K. O. (2004). Chemical and physical characteristics of meat/pH measurement. In W. K. Jensen, C. Devine, & M. Dikeman (Eds.), *Encyclopedia of Meat Sciences* (pp. 314–318). Oxford: Elsevier Academic Press.

Immonen, K., & Puolanne, E. (2000). Variation of residual glycogen-glucose concentration at ultimate pH values below 5.75. *Meat Science*, 55, 279–283.

Lawless, H. T., & Heymann, H. (2010). *Sensory evaluation of food: Principles and practices*. New York: Springer Science & Business Media.

Lawrie, R. A., & Ledward, D. A. (2006). Chemical and biochemical constitution of muscle. In *Lawrie's Meat Science* (pp. 75–127). Cambridge: Woodhead Publishing Limited.

Leygonie, C., Britz, T. J., & Hoffman, L. C. (2012). Impact of freezing and thawing on the quality of meat: Review. *Meat Science*, 91, 93–98.

Lindsey, P. (2011). An analysis of game meat production and wildlife-based land uses on freehold land in Namibia: Links with food security. TRAFFIC, East/Southern Africa.

McAfee, A. J., McSorley, E. M., Cuskelly, G. J., Moss, B. W., Wallace, J. M. W., Bonham, M. P., & Fearon, A. M. (2010). Red meat consumption: An overview of the risks and benefits. *Meat Science*, 84, 1–13.

McNeill, S., & Van Elswyk, M. E. (2012). Red meat in global nutrition. *Meat Science*, 92, 166–173.

Mossman, S. L., & Mossman, A. S. (1976). Wildlife utilization and game ranching. Report on a study of recent progress in this field in Southern Africa. International Union for Conservation of Nature and Natural Resources occasional paper no. 17. Morges, Switzerland.

Muchenje, V., Dzama, K., Chimonyo, M., Strydom, P. E., Hugo, A., & Raats, J. G. (2009). Some biochemical aspects pertaining to beef eating quality and consumer health: A review. *Journal of Food Chemistry*, 112, 279–289.

Neethling, J., Hoffman, L. C., & Britz, T. J. (2014). Impact of season on the chemical composition of male and female blesbok (*Damaliscus pygargus phillipsi*) muscles. *Journal of the Science of Food and Agriculture*, 94, 424–431.

Neethling, J., Hoffman, L. C., & Muller, M. (2016). Factors influencing the flavour of game meat: A review. *Meat Science*, 113, 139–153.

North, M. K., & Hoffman, L. C. (2015). Changes in springbok (*Antidorcas marsupialis*) *Longissimus thoracis et lumborum* muscle during conditioning as assessed by a trained sensory panel. *Meat Science*, 108, 1–8.

Onyango, C. A., Izumimoto, M., & Kutima, P. M. (1998). Comparison of some physical and chemical properties of selected game meats. *Meat Science*, *49*, 117-125.

Purchas, R. W., & Zou, M. (2008). Composition and quality differences between the *longissimus* and *infraspinatus* muscles for several groups of pasture-finished cattle. *Meat Science*, 80, 470–479.

Razminowicz, R. H., Kreuzer, M., & Scheeder, M. R. L. (2006). Quality of retail beef from two grass-based production systems in comparison with conventional beef. *Meat Science*, 73, 351–361.

Realini, C. E., Duckett, S. K., Brito, G. W., Dalla Rizza, M., & De Mattos, D. (2004). Effect of pasture vs. concentrate feeding with or without antioxidants on carcass characteristics, fatty acid composition, and quality of Uruguayan beef. *Meat Science*, 66, 567–577.

Rødbotten, M., Kubberød, E., Lea, P., & Ueland, Ø. (2004). A sensory map of the meat universe. Sensory profile of meat from 15 species. *Meat Science*, 68, 137–144.

Rowe, A., Macedo, F. A. F., Visentainer, J. V., Souza, N. E., & Matsushita, M. (1999). Muscle composition and fatty acid profile in lambs fattened in drylot or pasture. *Meat Science*, 51, 283–288.

Simopoulos, A. P. (1991). Omega-3 fatty acids in health and disease and in growth and development. *The American Journal of Clinical Nutrition*, 54, 438–63.

Simopoulos, A. P. (2002). Dossier: Polyunsaturated fatty acids in biology and diseases The importance of the ratio of omega-6/omega-3 essential fatty acids. *Biomedicine & Pharmacotherapy*, 56, 365–379.

Sundram, K., Hayes, K. C., & Siru, O. H. (1994). Dietary palmitic acid results in lower serum cholesterol than does a lauric-myristic in normolipemic. *The American Journal of Clinical Nutrition*, 59, 841–846.

Viljoen, H. F., De Kock, H. L., & Webb, E. C. (2002). Consumer acceptability of dark, firm and dry (DFD) and normal pH beef steaks. *Meat Science*, 61, 181–185.

Volpelli, L. A., Valusso, R., Morgante, M., Pittia, P., & Piasentier, E. (2003). Meat quality in male fallow deer (*Dama dama*): effects of age and supplementary feeding. *Meat Science*, 65, 555–562.

Von La Chevallerie, M. (1972). Meat quality of seven wild ungulates. *South African Journal of Animal Sciences*, 2, 101–103.

Warriss, P. D. (2000). *Meat Science: An introductory text*. Wallingford: CAB International Publishing.

Wiklund, E., Johansson, L., & Malmfors, G. (2003). Sensory meat quality, ultimate pH values, blood parameters and carcass characteristics in reindeer (*Rangifer tarandus tarandus* L.) grazed on natural pastures or fed a commercial feed mixture. *Food Quality and Preference*, 14, 573–581.

Wiklund, E., Pickova, J., Sampels, S., & Lundström, K. (2001). Fatty acid composition of M. longissimus lumborum, ultimate muscle pH values and carcass parameters in reindeer (*Rangifer tarandus tarandus* L) grazed on natural pasture or fed a commercial feed mixture. *Meat Science*, 58, 293–298.

Wilcox, S., Sharkey, J. R., Mathews, A. E., Laditka, J. N., Laditka, S. B., Logsdon, R. G., … Liu, R. (2009). Perceptions and beliefs about the role of physical activity and nutrition on brain health in older adults. *The Gerontologist*, 49, 61-67.

Wood, J. D., Enser, M., Richardson, M., & Whittington, F. M. (2008). Fatty acids in meat and meat products. In C. K. E. Chow (Ed.), *Fatty acids in foods and their health implications*. New York: Taylor & Francis Group.

Yancey, E. J., Grobbel, J. P., Dikeman, M. E., Smith, J. S., Hachmeister, K. A., Chambers Iv, E. C., Dressler, E. A. (2006). Effects of total iron, myoglobin, hemoglobin, and lipid oxidation of uncooked muscles on livery flavor development and volatiles of cooked beef steaks. *Meat Science*, 73, 680–686.

Chapter 6: The physical changes in eland (*Tragelaphus oryx*) *Longissimus thoracis et lumborum* and *Biceps femoris* muscles during ageing

6.1 Abstract

This study was conducted in order to establish the optimum ageing period for the *Longissimus thoracis et lumborum* (LTL)and *Biceps femoris* (BF) muscles of male and female common eland (*Tragelaphus oryx).* Six animals per sex were harvested on the Prinskraal farm near Bredasdorp in the Western Cape Province of South Africa. The two muscles were separated and randomly divided into one of nine ageing periods (2, 4, 7, 10, 13, 17, 21, 28, 35 days), vacuum packed and stored at 2-4 °C. Physical measurements included: pH, purge loss, cooking loss, drip loss, Warner-Bratzler shear force and CIELab surface colour. An increase in tenderness (57.3 N) was witnessed up to day 28 *post-mortem* of ageing. Both purge and cooking losses increased (2.5 and 1.3 % increase, respectively) throughout ageing, while cooking loss decreased (1.3 %). Meat surface colour turned brighter, more red (CIE a* = 15.6 on day 35) and yellow (CIE b* = 12.7 on day 35) with time. Hue-angle values only increased up to day 17 (41.4), whereas chroma continued to increase up to day 35 (20.2). Sex did not affect any of the measurements. Initially the BF was more tender, had less purge loss and higher CIE a* and b* values than the LTL, however as the ageing period progressed the differences between the muscles became less apparent. It appears that eland meat has to be aged up to a period of 28 days in order to achieve maximum tenderness and that no special distinction is needed between meat from female and male eland. Although moisture losses increased with days post-mortem, other positive changes linked to ageing such as increases in lightness and redness is advantageous.

6.2 Introduction

Climate change is a topic that has gained interest in recent years and at the same time has led to many uncertainties concerning South Africa's agricultural sector. In anticipation for the adverse weather changes that is said to become the norm some farmers have started moving away from traditional farming practises to more sustainable methods that incorporate advances in agricultural technology as well as alternative farming systems that are better adapted to the immediate environment (Otieno & Muchapondwa, 2016). One farming strategy that is particularly of interest involves a shift from farming with traditionally used livestock to a system that either focuses only on game animals or a mixed system between livestock and game animals. Incorporating game species in the farming model has many advantages such as better adaptation to the environment, more effective utilization of the natural vegetation and resistance to arid climates (Flack, 2013). Consequently the South African game ranching industry has shown a steady increase in growth over the past 15 years and is now the sixth largest contributor to the agricultural industry (Carruthers, 2008; Otieno & Muchapondwa, 2016). The main focus of the industry has always been on trophy and leisure hunting as well as live sales (Hoffman, 2007). With the latter decreasing in value over recent years, due to an increase in number of farms and thus animals available, farmers are pressured to look into alternative ways to utilize surplus animals. Together with the dependence of trophy hunting and ecotourism on the global economy, this has led to more uncertainty around the financial feasibility of game ranching. The sale of game meat has the potential to provide farmers with a more sustained income and at the same time supplement South Africa's red meat market.

Both supply and demand of game meat will need to improve if it is to make it onto supermarket shelves. Misconceptions about game meat need to be clarified so that the benefits can be conveyed to consumers (Hoffman et al., 2005). Moreover, the demand for game meat will have to be matched by a sustainable supply of consistent high quality products from producers (Hoffman et al., 2005; Hutchison et al., 2010). This necessitates specific research on the game species that have been identified for meat production instead of simply adopting methods that have been used for domestic livestock.

Optimization of tenderness is an important focus point for game meat producers since tenderness is one of the major aspects taken into account by consumers when accessing fresh meat quality (Grunert et al., 2004). Furthermore, consumers have the perception that game meat is tougher than that of traditional livestock (Du Buisson, 2006; Hoffman et al., 2004). Nonetheless it remains a challenge to accurately evaluate this quality attribute of the meat before purchase simply by looking at it, which often results in an unsatisfying eating experience by consumers. Together with this, most consumers have a misconception of what factors are important in determining the overall quality of meat (Resurreccion, 2002). In his study on consumer perceptions of beef, Grunert (2001) confirmed this scenario of consumer's quality expectation not corresponding to their eating quality experience. This was due to the fact that consumers tend to avoid cuts with higher visible levels of fat (both subcutaneous and intramuscular fat) when buying meat, although they prefer the taste and tenderness of fattier cuts (Frank et al., 2016).

Alternatively the factors that influence meat quality such as juiciness, flavour and tenderness can be improved by means of ageing (Monsón et al., 2005; Sitz et al., 2006). During ageing tenderization is caused by proteolysis of myofibrillar and cytoskeletal proteins as well as changes in the connective tissues (Chriki et al., 2013; Jeremiah et al., 2003). This can be achieved using various methods, but the basic techniques involve either vacuum, dry or permeable bag dry ageing. Vacuum ageing is most often used in the meat industry due to benefits such as lower ageing losses and convenience during storage and transport (Hodges et al., 1974; Warren & Kastner, 1992). Dry ageing is valued for enhancing flavour (Campbell et al., 2001; King et al., 1995), but factors such as careful control of the storage environment and higher losses during ageing can decrease profits (Degeer et al., 2009; Parrish et al., 1991). Bag dry ageing is a new and advancing technique that makes use of a water vapour permeable bag in which the meat is kept during the ageing period. This technique is beneficial because the sensory quality of the dry ageing technique is achieved together with decreased losses, risk of contamination and need for environmental control (Degeer et al., 2009; Lundesjö Ahnström et al., 2006).

Since vacuum ageing is most widely used in the industry (Smith et al., 2008), it would make sense to utilize the same technique for game meat if the idea is to produce it on a comercial scale. Since the eland is the largest of the game species considered for meat production it would be unwise to simply adopt ageing periods that have been established for other game animals or livestock of equal size. Therefore the objective of this study was to determine the optimum ageing period for maximum tenderness by vacuum packing portions from the *Longissimus thoracis et lumborum* (LTL) and *Bicep femoris* (BF) muscles. At the same time changes in ageing losses and colour of the meat was monitored so that results could be compared to farmed species of similar size and meat characteristics such as beef.

6.3 Materials and methods

6.3.1 Harvest and slaughter

Twelve (six male, six female) eland were harvested on the Prinskraal farm near Bredasdorp in the Western Cape Province of South Africa. Harvesting took place in accordance with the standard operating procedure (ethical clearance number: 10NP_HOF02). Animals were harvested on two separate occasions within the period of one month between the months of June and July 2016. After a kill shot to the head or chest, the animals were exsanguinated and transported to the slaughtering facilities to be skinned and eviscerated. Carcasses were then suspended in the cold truck (2-4 °C) for transportation back to the meat processing lab at the Department of Animal Sciences at the University of Stellenbosch. See Chapter 3 for more detail.

6.3.2 Sampling

Carcasses were transferred to a refrigerator (2-4 °C) upon arrival at the department and were processed the following day (day 2 *post-mortem*). Both parts of the *Longissimus thoracis et lumborum* (LTL) muscle were removed from the front and hind quarters as well as the whole *Biceps femoris* (BF) muscle from the hind quarters. This was done for the right and the left side of the carcass. Muscles from the right side were set aside for this trial and chemical and physical analysis (Chapter 4), while muscles from the left side were used in a sensory trial (Chapter 5). Both muscles were trimmed of subcutaneous fat and epimysium and then cut perpendicularly to the longitudinal axis of the muscle so as to divide it into nine equal portions that were randomly assigned to one of the nine ageing periods. Each portion was individually vacuum packed in a composite plastic (70 µm polyethylene and nylon; moisture vapour transfer rate of 2.2 g/m^2/24 h/1 atm, O_2 permeability of 30 cm^3/m^2/24 h/1 atm and a CO_2 permeability of 105 cm^3/m^2/24 h/1 atm) bag with a residual pressure of 5 mb (as per the machine gauge pressure reading) (Multivac, Model C200; Sepp Haggenmuller, Wolfertschwenden, Germany) and placed back in the refrigerator (2-4 °C) for the duration of the assigned ageing period.

6.3.3 Sample preparation

At the end of each ageing period, the muscle portions were taken out of the refrigerator and the vacuum packing removed. The portions were then blotted dry with paper towel to remove any surface moisture and then weighed to determine the purge loss. Subsequently each portion was cut into two centimetre thick steaks (minimum of three steaks) for determination of cooking loss, drip loss, Warner-Bratzler shear force and CIELab surface colour. Portions that were assigned to the two day ageing period (day of carcass processing) were treated the same as the other ageing period samples and also formed part of the physical analysis on the six major muscles (Chapter 4).

6.3.4 Physical analysis

6.3.4.1 pH

The ultimate pH (pHu) was measured for both muscles ~36 hours *post-mortem* after the muscles were removed from the carcass. This would allow sufficient time for the full resolution of rigor prior to measurement. pH was measured as close to the centre of each muscle using a calibrated (pH standard buffers at pH 4.0 and pH 7.0) Crison ICRI2502 portable pH meter.

Following the completion of each ageing period the pH was recorded for the samples after they had been removed from their individual vacuum bags and blotted dry. This measurement could then be compared to the pH that was measured before ageing.

6.3.4.2 Cumulative purge loss

Prior to vacuum packaging the weight of each portion was recorded. After the completion of the set ageing period portions were blotted dry with paper towels so as to remove any moisture on the surface. The weight was once again measured for each portion so that the amount of purge during the ageing period could be determined. This moisture loss was expressed as a percentage of the initial raw weight before ageing.

6.3.4.3 Surface colour

After ageing was complete the portions were cut into 2 cm steaks perpendicular to the direction of the muscle fibres so as to produce two to three steaks of equal size. Six colour measurements were taken at random locations after the steaks were left to bloom for 30 minutes (Honikel, 1998). The measurements were done in accordance to the CIE L*a*b* colour system (Honikel, 1998). The CIE L* (lightness), a* (green-red value) and b* (blue-yellow value) values were measured using a Color-guide 45°/0° colorimeter (BYK-Gardner GmbH, Gerestried, Germany). Thereafter the CIE a* and b* values were used to calculate the chroma value (saturation/colour intensity) and hue-angle (colour definition) by means of the following equations:

Hue-angle (°) = $\tan^{-1}$ (b*/a*)

Chroma (C*) = $(a^{*2} + b^{*2})^{0.5}$

6.3.4.4 Cooking loss

One steak was selected from each portion and weighed before it was suspended in a water-bath (model 102 digital electrical bridge thermostat; model 132A 40 l water-bath; Scientific, Roodepoort, South Africa) set to 80°C. To allow for complete cooking (internal temperature of 72 °C) the samples were left in the water-bath for 60 minutes before they were removed and placed in the refrigerator (2-4 °C) to cool down overnight. The following day they were removed from the refrigerator, blotted dry and weighed to determine the final weight. This weight could then be compared to the initial weight of the raw sample so that the moisture lost during cooking could be determined. The cooking loss was expressed as a percentage of the initial raw weight of the samples (Honikel, 1998).

6.3.4.5 Warner-Bratzler shear force

The tenderness of the meat was determined by using a model 3345 Instron Universal Testing Machine (Apollo Scientific cc, Alberta, Canada) fitted with a Warner-Bratzler blade. The Instron had a load cell of 5 kN and crosshead speed of 200 mm/min. The Warner-Bratzler fitting was 1.2 mm thick and had a triangular opening with a base length of 13 mm and a perpendicular height of 15 mm.

Six samples were taken from each cooking loss steak to be used for the Warner-Bratzler shear force test. Two scalpels fixed at a distance of 1 cm from each other were used to cut through the 2 cm thick steaks so as to produce a rectangular prism of 1 cm x 1 cm x 2 cm that ran parallel with the muscle fibres. Each sample was then individually cut by the Instron machine perpendicular to the longitudinal axis of the sample. The force in Newton required to cut through the muscle fibres was measured and the average of the six measurements was then used to determine the Warner-Bratzler shear force of each muscle (Honikel, 1998).

6.3.4.6 Drip loss

One steak from each ageing portion was used for a drip loss test to determine the water holding capacity of the meat. This was done by suspending the steak on a wire in an inflated polyethylene bag so as to catch any moisture extruded from the sample during this period. Samples were placed in the bags in such a way that it did not touch the sides, top or bottom of the bag. The samples were hanged in a refrigerator (2-4 °C) for 24 hours after which they were removed from the plastic bags, blotted dry and weighed to determine the final weight. The moisture lost during the suspension period was then used to calculate the drip loss as a percentage of the initial weight of the sample.

6.3.5 Statistical analysis

A three-factor factorial layout was used for this trial with a completely randomized design. Sex, muscle and ageing period were the three main effects that were tested as well as their interaction with one another.

The data was first subjected to normality testing by means of the Shapiro-Wilk test using SAS ™ statistical software (Statistical Analysis System, Version 9.4, SAS Institute Inc., Cary, NC, USA). Outliers that disrupted the normal distribution of the data were removed.

Main effects, interactions and correlations with a *P*-value equal to or less than 0.05 were regarded as being significant. Values are reported as the LSMeans ± the standard error of the mean (SEM).

6.4 Results

None of the interactions of the main effects had an influence on the pH. The main effects of sex and muscle had no significant influence on pH (Table 6.2). The pH did however change significantly over the 35 day ageing period but changes were inconsistent.

Second order interactions were found in the purge loss percentage for muscle by days (P = 0.043) (Fig. 6.2). There was no significant difference between sexes (P = 0.586) for purge loss. The LTL did experience more moisture loss than the BF ($P \leq 0.001$), but this was less than one percent. Purge loss increased from day four to day 28 ($P \leq 0.001$), where after no significant difference was present between the last two ageing periods (Table 6.2).

Table 6.1 Level of statistical significance (P - values) for the main effects of sex and muscle and their interaction for the ageing of eland meat.

Variable	Gender	Muscle	Gender*Muscle	Day	Gender*Day	Muscle*Day	Gender*Muscle*Day
pH	0.3565	0.251	0.2037	<0.0001	0.195	0.0620	0.4291
Weep loss (%)	0.5859	<0.001	0.7466	<0.0001	0.1967	0.0428	0.2289
Cooking loss (%)	0.5075	0.469	0.649	<0.0001	0.8165	0.7826	0.0328
Drip loss (%)	0.5047	0.1412	0.4054	<0.0001	0.6407	0.0310	0.8560
Tenderness	0.3051	0.0095	0.448	<0.0001	0.8772	0.0105	0.7800
l*	0.7287	0.7744	0.2781	0.0213	0.016	0.0910	0.8435
a*	0.3644	<0.0001	0.1122	<0.0001	0.8324	0.5888	0.1604
b*	0.3543	0.0013	0.0603	<0.0001	0.5448	0.4829	0.6678
Hue angle	0.5274	0.0011	0.2588	0.0065	0.828	0.5930	0.0833
Chroma	0.3525	<0.0001	0.0727	<0.0001	0.7393	0.5308	0.3429

Table 6.2 Eland muscle pH, cumulative purge loss, cooking loss, drip loss, Warner-Bratzler shear force and CIELab surface colour as per sex, muscle and ageing period (LSMeans ± SEM).

Main effects		**pH**	**Purge loss (%)**	**Cooking loss (%)**	**Drip loss (%)**	**Tenderness**	**L***	**a***	**b***	**Hue angle**	**Chroma**
Sex	**Female**	5.59 ± 0.012	2.9 ± 0.17	32.4 ± 0.3	1.2 ± 0.05	83.4 ± 2.43	34.4 ± 0.21	14.8 ± 0.25	12.5 ± 0.18	40.3 ± 0.22	19.3 ± 0.30
	Male	5.67 ± 0.024	3.2 ± 0.15	32 ± 0.32	1.2 ± 0.06	73.9 ± 2.7	34.7 ± 0.21	13.6 ± 0.3	11.7 ± 0.18	41.3 ± 0.38	18.0 ± 0.33
Muscle	**BF**	5.67 ± 0.024	2.6^{b} ± 0.14	32.4 ± 0.37	1.2 ± 0.06	73.5^{b} ± 2.18	34.5 ± 0.23	15.6^{a} ± 0.27	12.8^{a} ± 0.19	39.6^{b} ± 0.25	20.2^{a} ± 0.33
	LTL	5.60 ± 0.011	3.5^{a} ± 0.17	32 ± 0.24	1.2 ± 0.05	83.8^{a} ± 2.89	34.6 ± 0.2	12.8^{b} ± 0.23	11.4^{b} ± 0.15	41.9^{a} ± 0.32	17.1^{b} ± 0.25
Day	**2**	5.56^{c} ± 0.047		31.4^{bc} ± 0.83	0.7^{f} ± 0.13	94.5^{ab} ± 4.12	34.6^{ab} ± 0.39	13.3^{e} ± 0.47	11.2^{d} ± 0.27	40.4^{bc} ± 0.68	17.4^{e} ± 0.49
	4	5.54^{c} ± 0.047	1.7^{f} ± 0.21	33.3^{a} ± 0.57	0.9^{ef} ± 0.08	99.6^{a} ± 7.03	34.5^{ab} ± 0.47	13.4^{de} ± 0.54	11.6^{cd} ± 0.39	41.2^{ab} ± 0.56	17.7^{de} ± 0.65
	7	5.62^{b} ± 0.031	2.5^{de} ± 0.25	33.2^{a} ± 0.67	0.9^{def} ± 0.1	88.1^{bc} ± 7.62	34.2^{b} ± 0.41	14.1^{cde} ± 0.58	11.9^{bc} ± 0.32	40.7^{ab} ± 0.60	18.5^{cd} ± 0.63
	10	5.63^{b} ± 0.031	2.5^{e} ± 0.29	33.5^{a} ± 0.45	1.1^{cde} ± 0.12	84.3^{bc} ± 4.4	34.5^{ab} ± 0.42	14.1^{cd} ± 0.67	12.1^{bc} ± 0.44	41.0^{ab} ± 0.67	18.6^{cd} ± 0.78
	13	5.63^{b} ± 0.039	2.9^{cd} ± 0.32	32.6^{ab} ± 0.65	1.2^{c} ± 0.06	77.9^{cd} ± 3.96	33.8^{b} ± 0.52	13.8^{cde} ± 0.64	11.8^{c} ± 0.44	40.9^{ab} ± 0.68	18.2^{cde} ± 0.75
	17	5.64^{b} ± 0.027	3.1^{bc} ± 0.26	33.2^{a} ± 0.74	1.2^{cd} ± 0.08	73de ± 5.13	34.5^{ab} ± 0.38	14.3^{bc} ± 0.63	12.4^{ab} ± 0.41	41.4^{a} ± 0.63	19.0^{bc} ± 0.73
	21	5.74^{a} ± 0.036	3.4^{b} ± 0.28	31.6^{bc} ± 0.64	1.3^{bc} ± 0.11	66.7^{ef} ± 2.51	34.5^{ab} ± 0.45	14.1^{cd} ± 0.59	12.1^{bc} ± 0.4	41.0^{ab} ± 0.63	18.6^{cd} ± 0.67
	28	5.66^{b} ± 0.045	4.1^{a} ± 0.34	30.9^{c} ± 0.51	1.6^{b} ± 0.09	57.3^{f} ± 3.42	35.3^{a} ± 0.41	15^{ab} ± 0.57	12.9^{a} ± 0.35	41.0^{ab} ± 0.60	19.9^{ab} ± 0.64
	35	5.67^{b} ± 0.039	4.2^{a} ± 0.37	30.1^{c} ± 0.51	2^{a} ± 0.05	66.2^{ef} ± 3.41	35.2^{a} ± 0.57	15.6^{a} ± 0.29	12.7^{a} ± 0.19	39.5^{c} ± 0.88	20.2^{a} ± 0.67

LSMeans: least squares mean; SEM: standard error of the mean.

LTL: *Longissimus thoracis et lumborum*; BF: *Biceps femoris*; PM: *post-mortem*.

$^{a-f}$ LSMeans (within a main effect) with different superscripts differ significantly at $P < 0.05$.

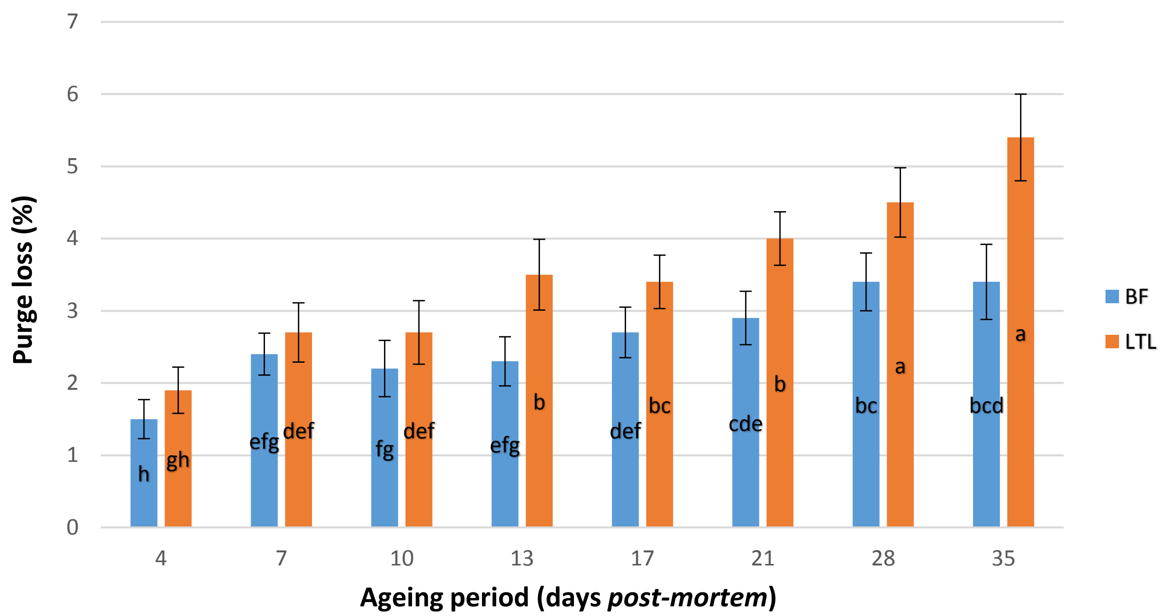


Figure 6.1 The purge loss (%) of eland *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles during ageing up to 35 days post-mortem.
[a-h] LSMeans (within a main effect) with different superscripts differ significantly at *P* <0.05. Error bars indicate the standard error of each mean.

Cooking loss was the only variable that showed 3rd order interaction for sex by muscle by days PM (*P* = 0.033). There were no noticeable trends in the data except for the fact that cooking losses remained fairly consistent (between 30-35%) for all interaction groups throughout the ageing period (Fig. 6.2 and 6.3). All interaction groups showed a slight decrease in cooking losses from day 17 onwards.

Despite the significant 3rd order interaction present in the cooking loss the least square means and standard errors for the main effects are given in Table 6.2. These values can still be interpreted seeing that the general trends for the main effects were not influenced by the interaction. From the table it is clear that there are no significant differences between the main effects of sex and muscle (*P* = 0.508 and *P* = 0.469, respectively), however the effect of days PM showed significant pairwise differences between day 17 and day 21, 28 and 35, confirming the trends seen in Figures 6.2 and 6.3.

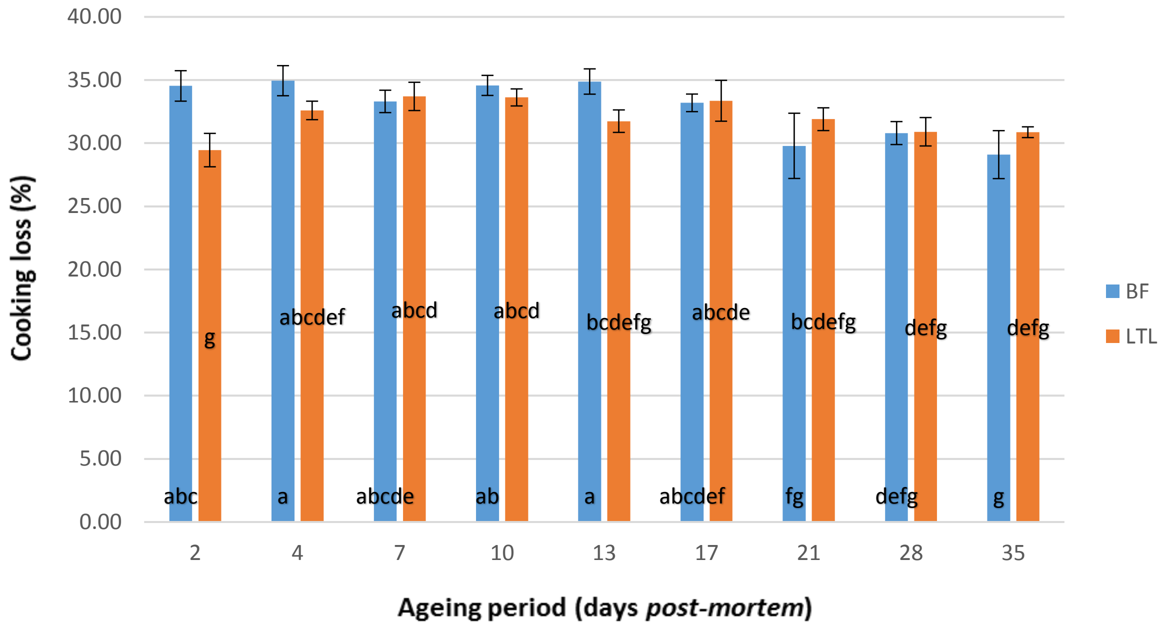


Figure 6.2 The cooking loss (%) of female eland *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles during ageing up to 35 days post-mortem.
[a-g] LSMeans (within a main effect) with different superscripts differ significantly at *P* <0.05. Error bars indicate the standard error of each mean.

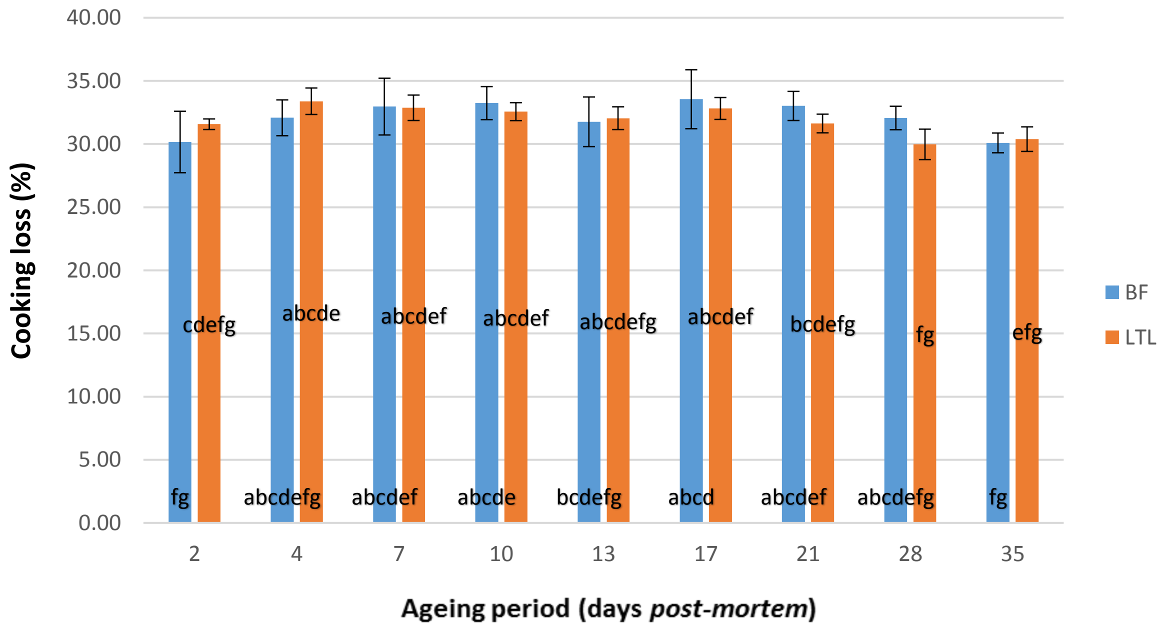


Figure 6.3 The cooking loss (%) of male eland *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles during ageing up to 35 days post-mortem.
[a-g] LSMeans (within a main effect) with different superscripts differ significantly at *P* <0.05. Error bars indicate the standard error of each mean.

Second order interactions were found in the drip loss percentage for muscle by days (*P* = 0.031) (Fig. 6.4). Following a similar argument as that applicable to cooking loss, the main effects of sex, muscle and ageing were interpreted individually (Table 6.2). There was no significant difference between sexes (*P* = 0.505) or muscles (*P* = 0.141), but drip loss followed a positive linear trend from day two to day 35 (*P* ≤ 0.001).

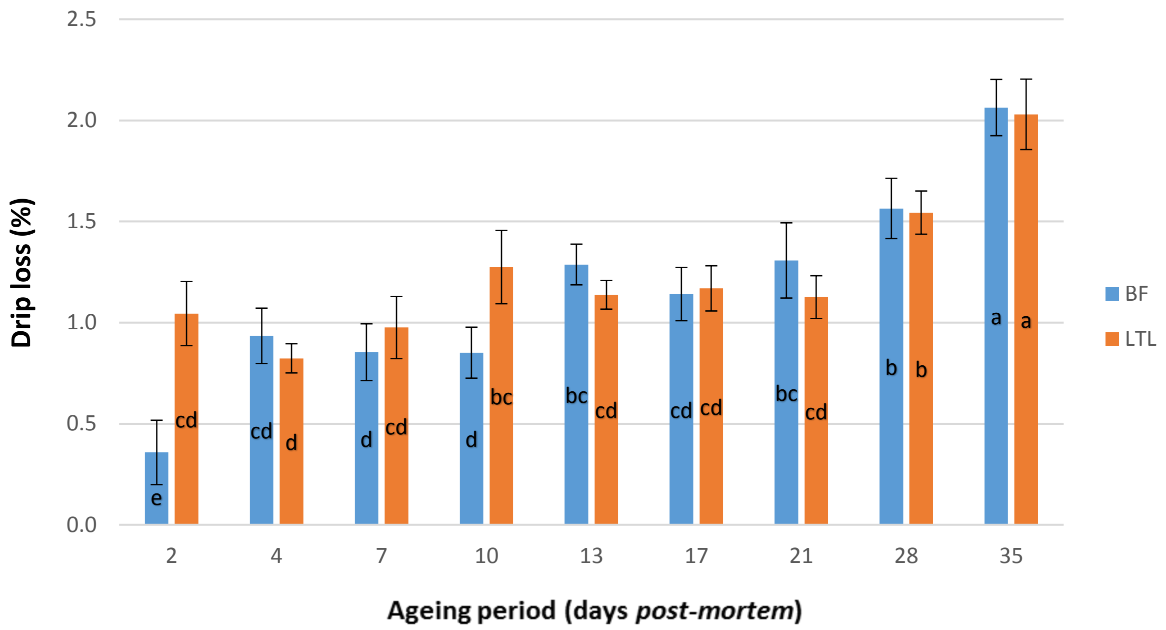


Figure 6.4 The drip loss (%) of eland *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles during ageing up to 35 days post-mortem.
[a-d] LSMeans (within a main effect) with different superscripts differ significantly at *P* <0.05. Error bars indicate the standard error of each mean.

There was no significant difference between sexes (*P* = 0.305), however second order interactions were found in the tenderness for muscle by days (*P* = 0.011) (Fig. 6.5). Both muscles showed a decrease in shear force up to day 28, with the LTL being tougher than the BF until day 21 of ageing. On day 28 the LTL had a slightly lower shear force than the BF and this remained the same until the end of ageing, however both muscles showed an increase in shear force on day 35. The BF was more tender than the LTL (*P* = 0.010). Tenderness improved from day four to day 28 (*P* ≤ 0.001) and then increased again on day 35.

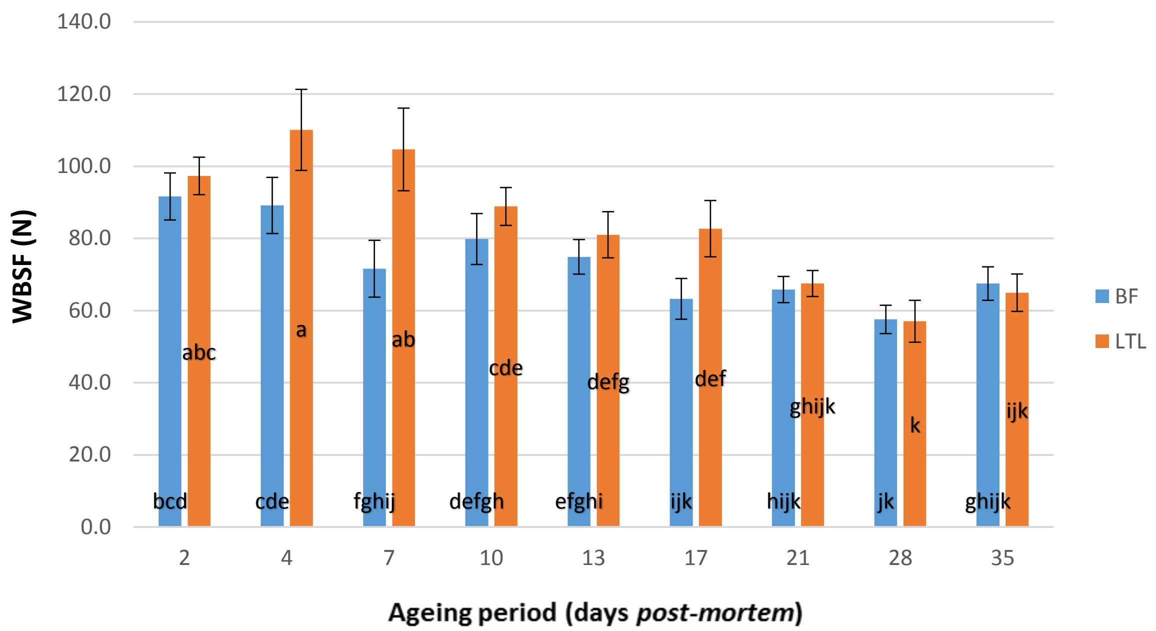


Figure 6.5 The tenderness of eland *Longissimus thoracis et lumborum* (LTL) and *Biceps femoris* (BF) muscles during ageing up to 35 days post-mortem.
[a-k] LSMeans (within a main effect) with different superscripts differ significantly at *P* <0.05. Error bars indicate the standard error of each mean.

Second order interactions were found in the CIE L* value for sex by days (*P* = 0.016) (Fig. 6.6). There was no significant difference between sexes (*P* = 0.729) or muscles (*P* = 0.774). There was no apparent trend for days PM, however the L* value significantly increased between 21 and 28 days PM (*P* = 0.021).

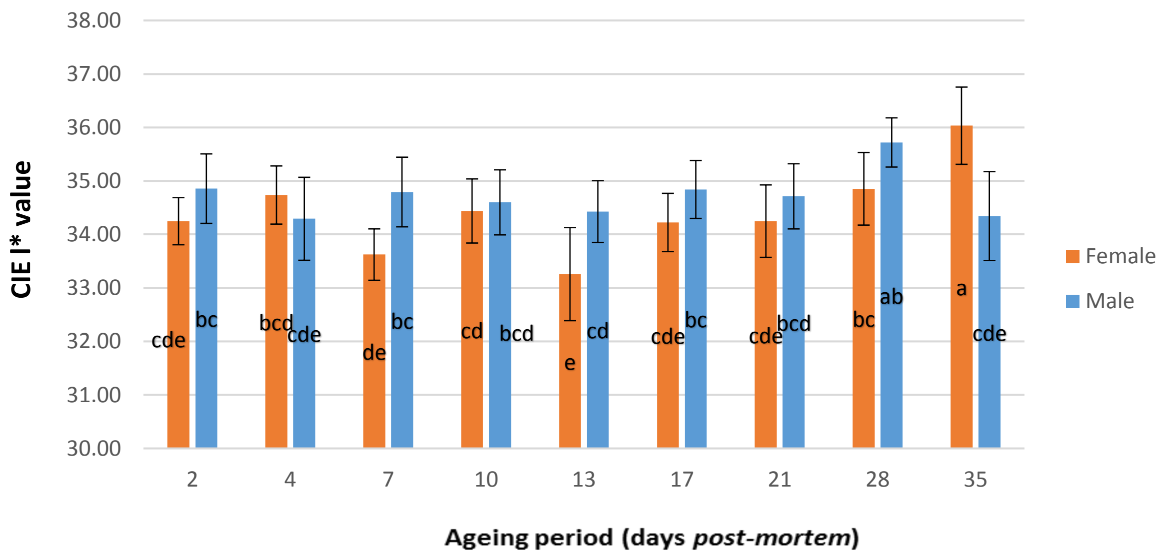


Figure 6.6 The CIE L* value of female and male eland meat during ageing up to 35 days post-mortem.

[a-e] Significant differences between ageing periods are indicated with different letters. Error bars indicate the standard error of each mean.

No interaction influences were seen for both the CIE a* and b* values, but both were effected by muscle (*P* ≤ 0.0001 and *P* = 0.001, respectively) and days PM (*P* ≤ 0.0001, for both). Both the CIE a* and b* values were higher for the BF muscle (Table 6.2). Both CIE values increased with every consecutive ageing period up to day 35 PM. Muscle affected both the hue angle and chroma values (*P* = 0.001 and *P* ≤ 0.0001, respectively). The LTL had a higher hue-angle and the BF a higher chroma value. Both values were affected by days PM (*P* = 0.007 and *P* ≤ 0.0001, respectively) and a clear increase can be seen for hue-angle over days PM, while chroma increased over the first period of ageing up to day 17 when it reached its highest point and then started to decline again.

6.5 Discussion

The main objective of this study was to quantify the optimal tenderness period of two major eland muscles that are suitable for consumption as such after vacuum ageing portions of each muscle for different periods PM. According to Shackelford et al. (1999) and Voisinet et al. (1997), meat with a shear force of less than 30.2 N is regarded as being 'tender', between 30.2 – 35.6 N as 'intermediate' and higher than 35.6 N as 'tough'. Destefanis and colleagues (2008) found that consumers are able to distinguish between tough and intermediate meat if the Warner-Bratzler shear force goes over 52.68 N and tender and intermediate meat if the reading is lower than 42.87 N. None of the muscles that were tested ever tenderized past the threshold value (<42.87 N) for tender. The lowest shear force value obtained for the eland meat was recorded on day 28 PM when the BF had a shear force of 57.5 N and the LTL was measured at 57.0 N. Thus even at its most tender the meat would be regarded as being tough by consumers. This was reflected by the relatively low tenderness scores awarded to the BF and LTL (37.1 and 38.5 out of a 100, respectively) by the trained panel in the sensory trial (Chapter 5), although it should be borne in mind that this trained panel evaluation was conducted on meat that had only been aged for 7 days prior to being frozen. The LTL of beef has been reported to reach optimum tenderness around 14 days of ageing, with a drop in tenderness of around 10-16 N over this period. The eland LTL took exactly twice as long to reach its optimum tenderness, even though the rate of tenderization was higher compared to beef. Similar rates of tenderization has been found for other game species, where the higher rate of tenderization was ascribed to increased proteolytic enzyme activity and more efficient proteolytic systems in venison compared to beef (Hutchison et al., 2010; North & Hoffman, 2015). Despite higher tenderization rates, eland meat did not reach the same level of tenderness than beef as the shear force at the start of the ageing period is more than double that typically reported for beef. The reason for this could be due to the fact that most beef carcasses are electrically stimulated, which increases the rate of glycolysis, thus the onset and completion of *rigor mortis* is achieved sooner and tenderization can start sooner (Hwang et al., 2003). With electrical stimulation the calpain system is activated earlier which is beneficial for longer ageing periods, but in most cases initial tenderness of muscles was also positively influenced by stimulation , possibly through physical disruption of muscle fibres (Drew et al.,1988; Hwang et al., 2003; Sorinmade et al., 1982). Wiklund and colleagues (2001) found that the tenderness of red deer meat was significantly influenced by electrical stimulation with lower shear force values up to the third week of ageing, although display life (a* value above 12) decreased.

Meat tenderness or toughness is known to be influenced by various *ante*- and *post-mortem* factors such as species, muscle activity, intramuscular fat and collagen content, ageing time, electrical stimulation, etc. (Koohmaraie et al., 2002). Of the numerous variables related to tenderness, Hawkins et al. (1987) ascribed 51% of the tenderness variation in their study to muscle traits, such as sarcomere length and percentage of moisture and fat.

Total insoluble collagen has previously been reported to be lower in game meat compared to beef (North & Hoffman, 2015; Seggern et al., 2005; Seideman, 1986; Torrescano et al., 2003), so the lack of tenderness can possibly be ascribed to low levels of intramuscular fat, although the role of electrical stimulation as typically applied to most beef carcasses should not be overlooked. Game animals tend to deposit fat around the visceral organs and have very little intramuscular fat (Talbot et al., 1965). Onyango and colleagues (1998) found less than 1% crude fat content in a comparative study between three game species, while Bartoň and colleagues (2014) found that male eland had a crude fat of 0.2 % and cattle 1.4 % in their comparative study. In the muscle comparison trial (Chapter 5) the BF had the highest crude fat percentage (1.75 ± 0.07), while the LTL had the lowest percentage (1.21 ± 0.08) of the muscles tested. This supports the fact that intramuscular fat contributes to tenderness, since the BF was tenderer than the LTL, particularly at the beginning of the aging periods evaluated.

Another factor of importance when it comes to tenderness is the percentage moisture lost. A portion of meat with less moisture will have a lower tenderness rating. Most of the water in lean muscle is found in between the actin and myosin filaments of sarcomeres, while only 10% is bound to hydrophilic protein groups and a further 5% in the extracellular space between muscle fibres (Lawrie, 1977; Warris, 2000). Ageing and cooking results in moisture loss because proteins and protein bonds are broken down and then release the water that was bound into the extracellular space. From here water is either extruded as purge, drip or cooking loss.

Both purge and drip loss increased over the ageing period up until day 28. Purge loss increased by almost 60% and drip loss by over 40%, which is in accordance with the above mentioned information regarding extracellular water and previous studies on game animals and beef (Hoffman et al., 2009; Hoffman et al., 2009; Neethling & Hoffman, 2014; Onyango, Izumimoto, & Kutimaa, 1998). Cooking loss slightly decreased from day 2 until day 28, which was expected as a larger portion of the total moisture was lost as purge and drip towards the end of ageing. The same has been found for other conditioned game meats (North & Hoffman, 2015) and a decrease in cooking loss percentage has previously been linked to an increase in tenderness as was seen in this study (Silva et al., 1999; Thomas et al., 2004). In comparison with beef the eland LTL had ten percent less cooking loss than what was found for beef after a 20 day ageing trial by Modzelewska-Kapitula and colleagues (2015).

The CIE L* value gives an indication of the brightness of the meat after blooming. An increase in the L* value was observed between ageing periods up until day 28, this together with the increase in a* and chroma values suggest that aged eland meat would have a brighter, redder and more saturated colour compared to meat that was not aged. The a* values were also above the established cut-off point of 12 for consumer acceptability as established by (Wiklund et al., 2001). These values are lower than what has been recorded for beef but is in accordance to what is generally expected for game meat (L* < 40, high a*, low b*) (Volpelli et al., 2003), although the a* and b* values are significantly higher and the L* value lower than what has previously been reported for eland meat (farmed) (Luděk Bartoň et al., 2014). These colour differences are to be expected when meat from farmed eland is compared to wild eland meat as similar differences have been found for farmed and wild deer, where the L* value was lower and the a* value higher for the wild animals (Daszkiewicz et al., 2015). Larger antelope species such as eland and oryx (*Oryx gazelle)* have previously been linked to lighter meat colour and smaller animals to darker meat (von La Chevallerie, 1972). The colour coordinates for the two muscles indicate that the BF will have a more saturated red colour than the LTL, as well as more yellowness. The LTL was less saturated but had a significantly higher hue angle, indicating a dull, browner colour compared to BF. The same has been found in some studies for these two muscles in beef (Onyango et al., 1998; Seggern et al., 2005). Overall both muscles experienced a positive change in colour attributes with consecutive ageing periods, although the BF had a slightly higher rating for most of these measurements.

6.6 Conclusions

Positive changes in the tenderness and CIE colour values were witnessed with ageing which will be beneficial if eland meat is to be commercially produced for public consumption since meat colour is one of the main aspects consumers use to visually asses meat quality (Hood & Riordan, 1973), while tenderness contributes to the palatability (Ouali et al., 2006). However tenderness did not reach a satisfactory level. Tenderness and juiciness of eland meat could potentially be lowered to a consumer satisfactory level by means of treatment with an inorganic salt solution (Du Buisson, 2006) as the application of more traditional methods such as electrical stimulation are not really practical in the field (Marais, 2013) and further research is needed on the long term effects of this method.

Although sensory and aroma attributes weren’t measured in this study it might be worth investigating since other studies on game meat has found an increase in undesirable metallic and liver-like flavours and aromas with a conditioning period of 28 days in springbok (North & Hoffman, 2015). This is especially of concern since maximum tenderness was only reached on day 28 PM in the eland. Therefore it might be useful to compare different ageing methods such as dry ageing versus vacuum ageing, since it has been found that consumers prefer beef that was dry aged because of superior juiciness, tenderness and flavour (Li et al., 2013).

During initial ageing measurements the BF muscle had superior colour and tenderness scores as well as less purge loss compared to the LTL, however as ageing progressed the differences between muscles became less apparent. As there was no significant differences between sexes for the different ageing periods, sex does not have to be taken into account when ageing meat derived from mature eland.

6.7 References

Ahnström, M. L., Seyfert, M., Hunt, M. C., & Johnson, D. E. (2006). Dry aging of beef in a bag highly permeable to water vapour. *Meat Science*, 73, 674–679.

Bartoň, L., Bureš, D., Kotrba, R., & Sales, J. (2014). Comparison of meat quality between eland (*Taurotragus oryx*) and cattle (*Bos taurus*) raised under similar conditions. *Meat Science*, 96, 346–352.

Campbell, R. E., Hunt, M. C., Levis, P., & Chambers, E. (2001). Dry-aging effects on palatability of beef *longissimus* muscle. *Journal of Food Science*, 66, 196–199.

Carruthers, J. (2008). "Wilding the farm or farming the wild"? The evolution of scientific game ranching in South Africa from the 1960s to the present. *Transactions of the Royal Society of South Africa*, 63, 160–181.

Chriki, S., Renand, G., Picard, B., Micol, D., Journaux, L., & Hocquette, J. F. (2013). Meta-analysis of the relationships between beef tenderness and muscle characteristics. *Livestock Science*, 155, 424–434.

Daszkiewicz, T., Hnatyka, N., Dabrowski, D., Janiszewski, P., Gugołek, A., Kubiak, D., Koba-Kowalczyka, M. (2015). A comparison of the quality of the *Longissimus lumborum* muscle from wild and farm-raised fallow deer (*Dama dama* L.). *Small Ruminant Research*, 129, 77–83.

DeGeer, S. L., Hunt, M. C., Bratcher, C. L., Crozier-Dodson, B. A., Johnson, D. E., & Stika, J. F. (2009). Effects of dry aging of bone-in and boneless strip loins using two aging processes for two aging times. *Meat Science*, 83, 768–774.

Destefanis, G., Brugiapaglia, A., Barge, M. T., & Dal Molin, E. (2008). Relationship between beef consumer tenderness perception and Warner–Bratzler shear force. *Meat Science*, 78, 153–156.

Drew, K. R., Crosbie, S. F., Forss, D. A., Manley, T. R., & Pearse, A. J. (1988). Electrical stimulation and ageing of carcasses from red, fallow and New Zealand wapiti-type male deer. *Journal of the Science of Food and Agriculture*, 43, 245–259.

Du Buisson, P. M. (2006). Improving the Meat Quality of Blesbok (*Damaliscus Dorcas Phillipsi*) and Springbok (*Antidorcas Marsupialis*). Master's thesis, Stellenbosch University.

Flack, P. (2013). *Hunting the Spiral Horns: Eland, Everyman's Elephant*. Johannesburg: Rowland Ward Publications.

Frank, D., Joo, S. T., & Warner, R. (2016). Consumer acceptability of intramuscular fat. *Korean Journal for Food Science of Animal Resources*, 36, 699–708.

Grunert, K. G. (2001). Færdigfedning af slagtekøer: *Rapport fra en forbrugerundersøgelse.*

Grunert, K. G., Bredahl, L., & Brunsø, K. (2004). Consumer perception of meat quality and implications for product development in the meat sector—a review. *Meat Science*, 66, 259–272.

Hawkins, R. R., Davis, G. W., Cable, J. K., & Ramsy, C. B. (1987). Fragmentation index as an early post-mortem predictor of beef tenderness. *Journal of Animal Science*, 64, 171–176.

Hodges, J. H., Cahill, V. R., & Ockerman, H. W. (1974). Effect of vacuum packaging on weight loss, microbial growth and palatability of fresh beef wholesale cuts. *Journal of Food Science*, 39, 143–146.

Hoffman, L. C. (2007). The Meat We Eat: are you game? In Inaugeral lecture. Stellenbosch, Western Cape, South Africa.

Hoffman, L. C., Mostert, A. C., Kidd, M., & Laubscher, L. L. (2009). Meat quality of kudu (*Tragelaphus strepsiceros*) and impala (*Aepyceros melampus*): Carcass yield, physical quality and chemical composition of kudu and impala *Longissimus dorsi* muscle as affected by gender and age. *Meat Science*, 83, 788–795.

Hoffman, L. C., Muller, M., Schutte, D. W., Calitz, F. J., & Crafford, K. (2005). Consumer expectations , perceptions and purchasing of South African game meat. *South African Journal of Wildlife Research*, 35, 33–42.

Hoffman, L. C., Muller, M., Schutte, D. W., & Crafford, K. (2004). The retail of South African game meat: current trade and marketing trends. *South African Journal of Wildlife*

Research, 34, 123–134.

Hoffman, L. C., van Schalkwyk, S., & Muller, N. (2009). Effect of season and gender on the physical and chemical composition of black wildebeest (*Connochaetus gnou*) meat. *South African Journal of Wildlife Research*, 39, 170–174.

Honikel, K. O. (1998). Reference methods for the assessment of physical characteristics of meat. *Meat Science*, 49, 447–457.

Hood, D. E., & Riordan, E. B. (1973). Discolouration in pre-packaged beef: Measurement by reflectance spectrophotometry and shopper discrimination. *International Journal of Food Science & Technology*, 8, 333–343.

Hutchison, C. L., Mulley, R. C., Wiklund, E., & Flesch, J. S. (2010). Consumer evaluation of venison sensory quality: Effects of sex, body condition score and carcass suspension method. *Meat Science*, 86, 311–316.

Hwang, I. H., Devine, C. E., & Hopkins, D. L. (2003). The biochemical and physical effects of electrical stimulation on beef and sheep meat tenderness. *Meat Science*, 65, 677–691.

Jeremiah, L. E., Dugan, M. E. R., Aalhus, J. L., & Gibson, L. L. (2003). Assessment of the relationship between chemical components and palatability of major beef muscles and muscle groups. *Meat Science*, 65, 1013–1019.

King, M. F., Matthews, M. A., Rule, D. C., & Field, R. A. (1995). Effect of beef packaging method on volatile compounds developed by oven roasting or microwave cooking. *Journal of Agricultural and Food Chemistry*, 43, 773–778.

Koohmaraie, M., Kent, M. P., Shackelford, S. D., Veiseth, E., & Wheeler, T. L. (2002). Meat tenderness and muscle growth: is there any relationship? *Meat Science*, 62, 345–352.

Lawrie, R. A. (1977). Meat: Current developments and future status. *Meat Science*, 1, 1–13.

Marais, S. (2013). Meat quality of electrically stimulated game under variable harvesting conditions in South Africa. Doctoral dissertation, Stellenbosch University.

Monsón, F., Sañudo, C., & Sierra, I. (2005). Influence of breed and ageing time on the sensory meat quality and consumer acceptability in intensively reared beef. *Meat*

Science, 71, 471–479.

Neethling, J., & Hoffman, L. C. (2014). Impact of season on the chemical composition of male and female blesbok (Damaliscus pygargus phillipsi) muscles. *Journal of the Science of Food and Agriculture, 94, 424-431.*

North, M. K., & Hoffman, L. C. (2015). Changes in springbok (*Antidorcas marsupialis*) *Longissimus thoracis et lumborum* muscle during conditioning as assessed by a trained sensory panel. *Meat Science*, 108, 1–8.

Onyango, C. A., Izumimoto, M., & Kutimaa, P. M. (1998). Comparison of some physical and chemical properties of selected game meats. *Meat Science*, 49, 117–125.

Otieno, J., & Muchapondwa, E. (2016). Agriculture and adaptation to climate change : The Role of wildlife ranching in South Africa Agriculture and adaptation to climate change. Economic Research Southern Africa, working paper no. 579.

Ouali, A., Herrera-Mendez, C. H., Coulis, G., Becila, S., Boudjellal, A., Aubry, L., & Sentandreu, M. A. (2006). Revisiting the conversion of muscle into meat and the underlying mechanisms. *Meat Science*, 74, 44–58.

Parrish, F. C., Boles, J. A., Rust, R. E., & Olson, D. G. (1991). Dry and wet aging effects on palatabiltiy attributes of beef loin and rib steaks from three quality grades. *Journal of Food Science*, 56, 601–603.

Resurreccion, A.V.A. (2002). Sensory aspects of consumer choices for meat and meat products. *Meat Science*, 66, 11–20.

Seideman, S. C. (1986). Methods of Expressing collagen characteristics and their relationship to meat tenderness and muscle fiber types. *Journal of Food Science*, 51, 273–276.

Shackelford, S. D., Wheeler, T. L., & Koohmaraie, M. (1999). Tenderness classification of beef: II. Design and analysis of a system to measure beef *Longissimus* shear force under commercial processing conditions. *Journal of Animal Science*, 77, 1474-1481.

Silva, J. A., Patarata, L., & Martins, C. (1999). Infuence of ultimate pH on bovine meat tenderness during ageing. *Meat Science*, 52, 453–459.

Sitz, B. M., Calkins, C. R., Feuz, D. M., Umberger, W. J., & Eskridge, K. M. (2006). Consumer sensory acceptance and value of wet-aged and dry-aged beef steaks. *Journal of Animal Science*, 84, 1221–1226.

Sorinmade, S. O., Cross, H. R., Ono, K., & Wergin, W. P. (1982). Mechanisms of ultrastructural changes in electrically stimulated beef. *Meat Science*, 6, 71–77.

Talbot, L. M., Payne, W. J. A., Ledger, H. P., Verdcourt, L. D., & Talbot, M. H. (1965). The meat production potential of wild animals in Africa: A Review of biological knowledge. Technical Communication No. 16. Edinburgh.

Thomas, A. R., Gondoza, H., Hoffman, L. C., Oosthuizen, V., Naudé, R. J. (2004). The roles of the proteasome, and cathepsins B, L, H and D, in ostrich meat tenderisation. *Meat Science*, 67, 113–120.

Torrescano, G., Sánchez-Escalante, A., Giménez, B., Roncalés, P., & Beltrán, J. A. (2003). Shear values of raw samples of 14 bovine muscles and their relation to muscle collagen characteristics. *Meat Science*, *64*, 85-91.

Voisinet, B. D., Grandin, T., O ’Connor, S. F., Tatum, J. D., & Deesing, M. J. (1997). *Bos Indicus*-cross feedlot cattle with excitable temperaments have tougher meat and a higher incidence of borderline dark cutters. *Meat Science*, 46, 367–377.

Volpelli, L. A., Valusso, R., Morgante, M., Pittia, P., & Piasentier, E. (2003). Meat quality in male fallow deer (*Dama dama*): effects of age and supplementary feeding. *Meat Science*, 65, 555–562.

Von La Chevallerie, M. (1972). Meat quality of seven wild ungulates. *South African Journal of Animal Sciences*, 2, 101–103.

Von Seggern, D. D., Calkins, C. R., Johnson, D. D., Brickler, J. E., & Gwartney, B. L. (2005). Muscle profiling: Characterizing the muscles of the beef chuck and round. *Meat Science*, 71, 39–51.

Warren, K. E., & Kastner, C. L. (1992). A comparison of dry-aged and vacuum-aged beef strip loins. *Journal of Muscle Foods*, 3, 151–157.

Warriss, P. D. (2000). *Meat Science: An introductory text*. Wallingford: CAB International

Publishing.

Wiklund, E., Stevenson-Barry, J. M., Duncan, S. J., & Littlejohn, R. P. (2001). Electrical stimulation of red deer (*Cervus elaphus*) carcasses - effects on rate of pH-decline, meat tenderness, colour stability and water-holding capacity. *Meat Science*, 59, 211–220.

Chapter 7: General conclusions

There was no significant influence of sex on the carcass measurements of the Cape eland (*Taurotragus oryx oryx*) used in this research. Harvesting took place during the wet, winter months of June and July when food is not at its optimum which could explain the low carcass dressing percentages that were recorded in comparison to other game species. The carcass yields do however compare favourably with similar sized livestock and large muscle cuts allow for better processing into value added products. A substantial portion of edible offal and sizable skins also adds potential value in the right markets.

Sex did not play a role in the physical or proximate composition of eland meat, however differences in muscle type were apparent. These differences, possibly linked to muscle anatomical location and rate of temperature and pH decline, were clearly seen with the physical measurements performed on each muscle. The SM (a large muscle, deep within the carcass) had the lowest pH_u and higher drip loss, cooking loss and chroma values. The IS (small muscle on the outside of the carcass) had the highest pH_u and displayed signs of DFD with the lowest drip and cooking losses and the lowest CIE lightness value. With the proximate analysis a low level of intramuscular fat and high moisture content was detected for all muscles, while the protein content was slightly lower compared to other game species although still in line with domestic species. In general the differences between muscles in terms of proximate composition were small enough to be ignored, however differences in physical measurements could be used as a guide for processing different muscles to obtain maximum value from the whole carcass.

During the sensory analysis sexes and muscles were compared and again no major differences were recorded for cows and bulls. The BF was scored higher than the LTL for most flavour and aroma attributes and was slightly tenderer. Overall eland meat received higher scores for beef-like aroma and flavour compared to less favourable attributes such as gamey, livery and metallic. The fatty acid profile of eland revealed a high amount of stearic acid which subsequently increased the level of SFA's although it is not as harmful to human consumers as other fatty acids in this group. Despite this the P:S ratio was still within the healthy limits and comparable to previous studies on game meat. The BF had higher levels of SFA's, MUFA's and PUFA's and consequently had around 30 % more fatty acids than the LTL. The BF also had a slightly better P:S ratio and n-6:n-3 PUFA ratio although the latter was significantly lower for both muscles compared to previous results.

Positive changes were witnessed in the WBSF and CIE colour values during the ageing trial up to day 28. Initial differences in muscles, that favoured the BF, decreased with consecutive ageing periods although both muscles failed to reach a satisfactory level for shear force. Ageing of the meat was not influenced by sex, indicating that distinction between females and males is not necessary.

As mentioned throughout this work there is a lack of research on the meat quality and characteristics of game species as is the case with eland. Therefore the purpose of this study was to gather base line data and information to aid in future research and marketing efforts. Needless to say, there is plenty of room for more in depth studies as well as new studies related to eland. These include: investigations into the influence of habitat and plane of nutrition on the carcass composition, chemical and fatty acid profiles of eland; the use of castration and its effects on factors such as fat content and dressing percentage; comparisons between Cape eland and other sub-species of common eland or between eland and cattle in the same rearing conditions. Furthermore it would also be beneficial to determine the collagen composition of eland meat to see if it could have an influence on the shear force. Alternative ageing methods and brine injections are also proposed as a ways of potentially increasing the tenderness. The cholesterol content would also be useful for determining the overall healthiness. Recommendations for repeating this study would include increasing the sample size as well as more specific classification of animal age, if possible, so as to test its influence on the different properties of the meat.

The cape eland has proved itself to be a strong contender for domestication and could aid in providing food security in African countries. Its carcass and meat attributes are similar to beef and the meat is of high nutritional quality. This together with its docile nature and centuries of environmental adaptation, makes this specie an ideal alternative or substitute to traditional livestock farming in areas with harsh climates and little resources.